JOURNAL OF THE
BOSTON SOCIETY
OF
CIVIL ENGINEERS

DECEMBER - 1932

VOLUME XIX NUMBER 10

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Published Monthly, except July and August, by the Society
715 Tremont Temple, Boston, Massachusetts

Subscription Price, $4.00 a Year (10 Copies)
50 Cents a Copy

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Entered as second-class matter, January 15, 1914, at the Post Office at Boston, Mass., under Act of August 24, 1912.

Acceptance for mailing at special rate of postage provided for in Section 1103, Act of October 3, 1917, authorized on July 16, 1918.

The Society is not responsible for any statement made or opinion expressed in its publications.

Boston
Wright & Potter Printing Company
32 Derne Street

JOURNAL OF THE
BOSTON SOCIETY OF CIVIL ENGINEERS

Volume XIX DECEMBER, 1932 Number 10

DISCUSSION OF THE "REPORT OF THE COMMITTEE ON FLOODS" OF THE BOSTON SOCIETY OF CIVIL ENGINEERS

The Report of the Committee on Floods was printed in the September, 1930, Journal of the Boston Society of Civil Engineers. Discussion of this report, as printed herein, was presented at the meeting of the Society held on November 19, 1930.

Following are the names of those taking part in the discussion: Gerard H. Matthes, Joseph Watson Gross, J. H. Kimball, Robert E. Horton, Jacob A. Harman, Adolph F. Meyer, C. S. Jarvis, W. P. Creager, R. W. Davenport, Robert Follansbee, Leroy K. Sherman, Harold K. Barrows, S. Stanley Kent and Arthur T. Safford.

The John R. Freeman Committee, of which the late John R. Freeman was chairman, has allotted a portion of the income of the Freeman Fund for the publication of the Discussion of the Report of the Committee on Floods.

Discussion

Gerard H. Matthes:* The Society is to be complimented on the excellence of the report submitted by its Committee on Floods, and congratulated for being able to publish it through the generosity of Mr. John R. Freeman. The report is unusually broad in scope, and bears evidence of much painstaking labor. Of especial interest to the speaker is the closing chapter on "Cost and Economic Phases." It is on the latter subject that he wishes to submit a few comments.

It is pointed out by the Committee that an appreciable amount of flood reduction occurred in 1927 on those streams which are provided with large storage reservoirs for power, although no special effort was made to absorb flood peaks in them. The practicability of deriving a fair amount of flood reduction from this source in the future, as suggested by the Committee, is of considerable interest, as similar plans have been suggested on many rivers in the United States. Less is heard nowadays concerning the incompatibility of reservoir operation for such dual purposes except on certain streams. Granting the physical practicability of the plan, there is, however, the danger of postponing unduly the consummation of effective flood control if the latter is to come about solely as a by-product of water power development. This aspect varies widely in different parts of the United States. Conceivably, the situation in New England in this respect can be viewed more optimistically than in those States where cheap steam power production is now threatening to retard, if not to prevent, the development of water power.

The Committee's conclusions — to the effect that large expenditures for flood control, such as were made in the Miami River Valley in Ohio, are not likely to be warranted in the case of the New England valleys — appear to be sound. The speaker would go a step further and say that the New England valleys belong in that large category of river valleys in the United States in which complete flood protection will never be justified for economic reasons so long as their development remains, in general, as it is today. This sweeping statement finds support in the many negative reports that are being made regarding the advisability of providing flood control on various streams throughout the country. The reason appears to be that flood control, at best, is a costly undertaking warranted only in special cases. In most valleys the density of settlement, and the value of real property and public improvements in need of protection, taken collectively, are not sufficient to warrant building costly control works, and this is especially true in valleys like those of New England, where great devastating floods are rare occurrences.

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* Consulting engineer. Temporary address, care of United States Engineer Office, Norfolk, Va.

It is well to recognize, also, that the Miami Valley plan of flood protection, however excellent it may be, rarely has proved to be a useful plan to copy. It was made possible by a fortuitous combination of physical, economic and psychological factors which it would be difficult to duplicate elsewhere, and it is doubtful if the psychological factor, which was the deciding one in the combination, could be duplicated today in the Miami Valley, assuming the existing control works not built.

Damage statistics are set forth in the report in considerable detail, and these cover property damage and other direct losses, also economic losses. No attempt appears to have been made to evaluate those intangible losses and indirect forms of damage which usually grow out of great flood disasters. Such items are confessedly difficult to obtain and estimate, but are known to be large, often amounting to as much as the physical damage. Viewed from this angle, the Committee's conclusions as regards justifiable cost of flood control might be considered as being too conservative.

The Committee's approach to the matter of permissible cost of flood control is predicated largely, if not entirely, on the amount of flood damage that occurred in 1927. The method employed is that of capitalizing the average annual flood loss and using this as the outside limit of expenditure justified for protective works. Although this method is entirely in keeping with accepted practice, the speaker doubts whether it applies to the New England flood conditions except, possibly, in a few isolated cases. He has reason to believe that this method, which today is used so extensively, is, after all, not of general applicability. It is based on the premise that flood damage is an intermittently recurring form of loss that can be estimated years ahead. The history of floods does not bear this out. One of the principal objects of this discussion is to throw light on this phase of flood control economics. The remarks which here follow are general in nature and in no sense intended as a criticism of the Committee's report.

Generally speaking, economic benefits derived from flood control are of two kinds indirectly related to each other: (1) the prevention of physical damage and other forms of direct loss, (2) the restoration of property values to normal. Of these two, the latter affords a tangible and fairly definite basis for determining the value of flood control, and in projects where the cost of the works must be assessed against the properties benefited, it usually permits of determining the assessments on individual properties readily and equitably. Mere damage statistics, on the other hand, appear to afford no safe criterion as to what flood control may be worth. This is because there is no relation between the magnitude of a flood and the damage which it occasions. It would be strange, indeed, if ten years hence a flood of the same magnitude as that of 1927 should inflict the same kind or amount of damage as occurred in 1927, assuming only normal changes to have taken place in the valleys affected, in the meantime.

There is a constant evolution in man's use of the rivers and their flood plains. In early days, when settlement took place mainly along those streams which were navigable, the losses of life that occurred during great floods were extraordinarily large considering the sparsity of the population of those days. This was because the early settlers lived often in too close proximity to the banks of the streams which figured so prominently in the daily routine of their lives. The changes that have taken place since that time are such that today floods of the same magnitude on these streams take few lives. The history of the smaller non-navigable streams shows the opposite tendency. This is because in the smaller valleys settlement has increased and still tends to increase. But this is not true of the broad flood plains of our larger rivers, where high stages are frequent and the flooding of lowlands is an accustomed sight.*

As further instances of this evolution, consider the canal systems that paralleled so many of our eastern rivers during the first half of the last century. Built at great cost, considering the times, they were in nearly all cases located at elevations too low to escape washouts by floods. It was the repeated damage of this kind — not the advent of the railroads, as commonly supposed — that put most of the old canals out of business. The bankrupt condition of the canal companies, due to the frequent destruction of their dams and embankments by floods, made it easy for the railroads to buy many of them out. Once located on the same rights of ways, the railroads next became the sufferers from washouts. A quarter of a century later these same railroads reported less trouble from floods; although floods had not decreased, tracks had been raised. Some of our leading railroads, originally located on canal towpaths that were subject to frequent overflow, now have their tracks well above the highest known flood levels, and rarely suffer a washout. The Pennsylvania Railroad system's main lines in the State of Pennsylvania may be cited as the best example of this kind.

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* The Mississippi River is not included in these statements, the conditions there being in a distinct class by themselves.

On the subject of roads and bridges, we find that in this automobile age, highways have become such costly things, and the traffic over them so important, that inundations and washouts have become intolerable, whereas twenty-five years ago roads when flooded were easily repaired and traffic could afford to wait.

Man, sometimes, profits from the lessons taught him through bitter experience, and so, after great floods, it is not uncommon to find him shifting his residence to higher ground, building his bridges higher, his dams stronger, and making highways and railroads less vulnerable to the onslaughts of high waters. Flood damage is thus likely to be materially lessened and the need for flood control decreased. No better example could be cited than the reconstruction work that has been going on since 1927 in Vermont.* The speaker knows of many localities in the United States where similar transitions have taken place, or where man has adjusted himself to withstand the rigor of floods without material damage to himself. He recalls inspecting the factories within the flood zone along the Schuylkill River at Manayunk, Pa. The managers, without exception, declared that there was no need of flood control, although frankly admitting that high water frequently entered the lower floors of their factories. These floors contained no machinery or other valuable equipment, were used mainly as shipping rooms, and, at times of high water, could be quickly cleared and then deliberately turned over to the elements, without involving any monetary losses to the owners. Similar conditions exist elsewhere. An interesting case is the removal of the large Ingersoll Rand Company's plant from the Lehigh River Valley, where it had suffered great damage from floods, to high ground at Phillipsburg, N. J. This removal, made at great expense, is stated to have been solely for the purpose of ridding the plant of further flood damage.

When analyzed with respect to historical sequence and psychological aspects, the history of flood damage forms a chapter too vast and kaleidoscopic to warrant enlarging on here. But enough has been said, it is believed, to demonstrate the transitory nature of flood damage, and to justify the statement that flood damage statistics from one or two great floods, as so often used, furnish no safe index to the permissible cost of permanent protection.

Some kinds of flood damage can be foreseen but not guarded against at any reasonable price, and there is no strictly economic measure that offers a cure. Agricultural losses, for the most part, are of this kind. The farmer who buys lowlands and prays that overflow may take place at certain times so it may enrich his land without hurting anything is forever gambling against the possibility of a late flood destroying his crops. Recent inquiries conducted by the speaker in Virginia show that there appear to be few farmers who would be willing to pay as much as one dollar per acre per annum for permanent protection against floods. Flood damage in the shape of ordinary crop losses therefore offers but a weak argument in favor of flood control. But agricultural damages, consisting of soil erosion, gravel deposits on fertile lands, or flooding of valuable orchards, cause land values to depreciate, and if the areas affected are large, expenditures for protective measures may be warranted.

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* See in this connection the papers on "Reconstruction of Vermont Highways and Bridges," in JOURNAL of the Boston Society of Civil Engineers, December, 1928.

There are instances where flood control is warranted solely on the basis of flood damage. This is true where the damage is not of a transitory character but more or less unavoidable, of frequent recurrence, and definite in amount. Interference with sewage disposal and storm-water drainage in cities is of this kind; also interruptions in public utility service and in transportation systems of various kinds involving appreciable economic losses. In such cases the average annual flood loss, capitalized, becomes a fair criterion of the cost of flood control that would be warranted, and such cost would logically be met from municipal funds. The Committee appears to have recognized this category when it states that improvements for flood control may be warranted in New England in localities where frequent overflows cause constant economic losses.

Aside from cases of this kind, however, damage statistics are mainly useful for conveying an idea of the magnitude of a disaster like that of 1927, and for making appeals to municipalities, Legislatures and the Federal government for action of some kind. Without such figures, appeals to public authorities would carry little weight. In some cases, damage statistics can be interpreted only as warnings that man's encroachment on nature's pathways for floods has transgressed beyond safe and reasonable limits, or that structures such as properly belong within a flood plain, like bridges, dams, mills, power plants, highway and railroad embankments, should be built stronger or higher. In the last analysis, such statistics fail to serve as a basis for ascertaining the depreciation that has taken place in the selling value of real estate as the result of flood damage. Only direct appraisals can determine the amount of such depreciation.

The Committee foreshadows the need of legislation which would permit of the formation of storage regulation districts in which the cost of flood control would be assessed upon those benefited. This emphasizes the importance of making estimates of the extent to which property within and immediately adjacent to flood zones has declined in value, or, to put it differently, to estimate the extent to which property values would be benefited if complete protection against all future floods were to be provided. The speaker appreciates the fact that to have ascertained the amounts of such depreciation, or, conversely, benefits, clearly would have been outside the scope of the Committee's duties. He does not, therefore, raise this point in criticism of the Committee's report, but only to focus attention on the desirability of urging the proper authorities to inventory the depreciation that has taken place in property values, in order to determine whether sufficient benefits can be counted on to warrant the formation of storage regulation districts. The sooner such appraisals are made, the less difficulty will be experienced in differentiating between depreciation due to the flood and that incident to the present business depression.

In the Miami Valley the cost of the flood control works was assessed in two distinct forms: (1) as a flat tax added to city and county taxes; (2) in the form of special assessments levied on all properties benefited by reason of restoration of their market values. Each of these two forms of taxation roughly aggregated about half the total sum expended for flood control. In apportioning these assessments no trouble and expense were spared to determine the true depreciation of property values. The benefit of flood protection for each separate piece of property was equated to the depreciation which its fair market value had suffered. But no attempt was made to ascertain the extent of its physical damage. Immediately after the flood of 1913 a rough inventory placed losses of all kinds at approximately $100,000,000, and the loss of life at between 500 and 600. What the true losses were never will be known. However, the fact that property values in the flooded zone were estimated to have depreciated as much as 40 per cent, gave assurance, at the outset, that the spending of large sums for protection would be warranted.

Of interest, in this connection, is the fact that the actual physical damage to any one piece of property caused by the flood of 1913 was held to have no identifiable relation to the benefit accruing to it from flood protection. The practical considerations underlying this principle are best understood by reference to a concrete example. Let us assume two neighboring properties within the flood zone, similarly situated as regards depth of flooding, and having improvements exactly alike. Before the flood these properties commanded the same market price, the same rental value, and had the same assessed valuation. During the flood it happened that one residence was occupied by a prosperous family, and that the other was vacant. In the occupied house the flood waters created veritable havoc. Besides damaging the house, yard and garage, it ruined valuable furniture and rugs, priceless collections of books and antiques, and caused also the death of valuable household pets. In the garage, high priced automobiles were ruined, and in the yard and garden costly shrubbery and exotic plants were killed. At the peak of the flood water rose into the attic and forced the family to retreat to the roof, where, abandoning all their possessions, they were compelled to wait in the rain throughout the night, finally to be rescued the next morning. The privations and exposure so suffered caused some of them to die from pneumonia while others never regained their health. The impaired earning capacities of the surviving members caused their respective lines of business to decline, and this in turn was reflected in the prosperity of the community. Here, then, is a case where physical damage, indirect losses and intangible damage combined to run up a staggering total. But in the house next door the damage was slight, affecting mainly floors, plastering and wall paper, and further included such items as the pumping out of the cellar and sundry damages requiring minor repairs. A few hundred dollars would probably represent the total damage to this property.

After the flood, the status of these two properties may be summed up as follows: Irrespective of the damage that occurred at each, their rental values, now greatly reduced, remain alike, for one property still is as desirable as the other. Their market values remain alike, having depreciated by like amounts. Assuming complete flood protection to be provided, these properties would be benefited alike by having their original market values restored. Consequently, special assessments levied on them to meet the cost of flood control would have to be equal in amount. The important point to note is that neither the physical damage to the real estate nor the damage to individuals and to their business can be taken into account in computing the assessable value of the benefits to be derived from flood protection.

Summarizing, it appears to the speaker, in view of the transitory character of flood damage, and of the desire to plan flood protection for the benefit of posterity as well as for present needs, that engineers should use caution in applying the mathematics of capitalized values to any and all types of flood damage. The method does apply in restricted localities, but seems to lead to inconsistencies when applied to entire flood zones or regions affected by widespread flood disasters. If used at all, damage statistics should be purged of items like agricultural losses and all that is transitory in character or may be regarded as mere symptoms of man's temporary maladjustment to his environment.

In the great majority of cases flood damage must be written off as the price of experience, — the price man pays for having established himself within a flood plain, or for having underestimated the magnitude of the floods with which he must cope.

In closing, the speaker wishes to express the hope that some time in the march of civilization, flood zones like those in New England will be marked with prominent tablets along the highways and on public buildings, indicating the height to which great floods have been known to rise, and perhaps reciting the loss of life and property that resulted. Such tablets would carry an ever needful message to grown-ups and school children alike, and would go far toward educating the public and saving needless loss of life and property in future floods.

JOSEPH WATSON GROSS:* Mr. Chairman and Members of the Boston Society of Civil Engineers: I came here this evening as a visitor, with no intention of taking part in the discussion. I came to learn of your flood conditions on the Atlantic coast.

I am fortunate in having in my employ one of your own members. When your report came out he brought it to me and said, "Chief, there is something you will be interested in." My interest certainly was aroused, and particularly in regard to the method of determining from the hydrograph the amount of the flood. It is one which we have not used, and it does not seem applicable to our conditions.

The Sacramento Valley cannot be compared with your areas here, because of the sizes of the individual streams contributing to the flood flow. The size and slope of the watershed has a great deal to do with the intensity of flood run-off. The Sacramento River itself has five principal tributaries. In summer we have practically no run-off, and such as there is, is largely utilized for irrigation purposes. To give you an idea of the variation in flood flows I will mention the normal summer flow in the navigable portion of the Sacramento River as about 600 second feet. Our average winter flow is about 60,000 second feet in the same stream. The maximum anticipated flood for which we are now designing all of our works — and this figure is one which some of the more conservative engineers have advocated, although we are not satisfied with it — is in excess of 600,000 second feet. So we get a variation of from 600 to 600,000 second feet in the same locality.

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* Municipal and Reclamation Engineer, Sacramento, Cal.

So many subjects have been touched upon which are similar to the problems we have to consider on the Pacific coast that I wanted to add my little word of warning to that of Mr. Matthes relative to some of the things we think important on the Pacific coast and more especially in the Sacramento Valley. I want to commend Mr. Matthes in making his last suggestions regarding the psychological effect on people in having repeatedly brought before them the amount and extent of flood damage and the loss of life, all of which cannot be overestimated.

Mr. Matthes called to our attention the fact that in the New England States you have no method at this time of effecting a political organization which can finance flood control works. That condition is unbelievable to me. It is our everyday procedure. We have in California some half dozen different types of political districts which we can use for the purpose of financing flood control works. For the protection of agricultural lands we have what are termed "reclamation districts." These districts obtain their right to govern from the county. A group of landowners, believing that their land is susceptible of reclamation, apply for permission from the governing body which delegates to that district, through its board of governors, a part of the county governmental authority. Thereafter that body employs engineers, legal talent and contractors to do the work. That district can start the work without any money in the treasury. Its warrants are legal tender, and the money is raised either by direct assessment or by bond issue, the retirement or interest charges being made by assessment against the land. The board of directors, or "trustees" as they are called, are careful and thoughtful to the best of their ability, but unfortunately the agriculturists are not engineers or financiers, and it requires great diplomacy to get them to act as they should under certain circumstances. The money involved must go to the county treasury, and the expenditures must bear the approval of the county commissioners. Control of expenditures is provided, and disgruntled property owners may protest and the board of advisors may determine whether or not they should approve particular bills. The district must have its plans approved by the State Reclamation Board as to the size of levees and the type of levees, and by the United States Army Engineers, to prevent interference with navigation.

We have in Sacramento County perhaps thirty-five of those districts. The area of the individual tracts runs from 4,000 to 60,000 acres to a district. The benefits are assessed against the property by the board of commissioners, not the board of directors, but by outside people — usually outside engineers. These benefits are determined mainly by the soil characteristics, the soil elevation, contours and availability of drainage. The costs are usually equitably distributed, but the costs are high. Fifty cents an acre, or a dollar an acre, will not pay interest charges. Fifty dollars to one hundred dollars an acre is more nearly the figure of the cost of reclamation. For municipal reclamation the cities do their own work. Many pay the charges out of a general fund, or a bond fund may be raised in a similar manner as all municipal taxes are raised, — upon the value of the property.

We have water storage districts, irrigation districts and water supply districts. All of them are the means by which we can effect those things of which Mr. Matthes has spoken. It is almost unbelievable to me that you have not met that same demand in New England.

I am going to take exception to what Mr. Matthes said with regard to the co-ordination of power development and flood control. That may be all right in New England, but not on the coast. I must differ with him because of the psychological effect. If a community is to assist in financing a partial flood control project by means of reservoirs used co-operatively with some other interest, that idea must be placed before the voters in such a light that it can be financed. The boosters will be forced to declare that "These are life preservers. They will make you free from flood for ever." But you will be free only until the next flood, that is, in the West. Possibly this would not be the case in the East.

We have had that same problem with respect to the American River in Sacramento. The American River, like the Sacramento River, varies greatly between low flow and high flow. Low flow at our critical gaging station, where the stream empties into the main stream from the mountains, may be almost nothing — usually less than 100 second feet — in summer time. The maximum will be 120,000 second feet. A number of years ago, as deputy city engineer of Sacramento, I attempted to get that maximum figure raised to 180,000 second feet for purposes of design. Some thought that was too much, and that figure still stands. But unfortunately in 1928 the stream delivered 184,000 second feet just for exhibition purposes. That flow comes down in a channel designed for 120,000 second feet. The plan we had proposed was for regulated power and flood control, and by the accepted practice of analysis it was determined that the flood flow could be diminished to 100,000 second feet by the construction of a dam "so high." Personally, I would like to see it constructed, because it would afford some means of flood protection. That dam with the gates closed would hold 13 hours of the maximum flow, but the stream continues to flow at flood for more than 36 hours usually. Can you imagine the mental attitude of the people in that city, in case that dam were built and operated, and the normal flow reduced to down around 30,000 or 40,000 second feet? The channel becomes used to that 30,000 or 40,000 flow and encroachments are made on the banks. Every one strives for it. That condition has existed for some ten years and a fine channel has resulted. Then 36 hours of flood flow occur, and for 13 hours the reservoir holds back the waters, then you begin to get the maximum flow, and through that channel planned to take 100,000 second feet of flood flow there are 180,000 second feet passing down. The people will say, "Your works are not satisfactory." A study was made of that particular stream, and the amount of storage advocated by the first board of engineers — all fine men — was 359,000 acre feet, and the amount to be devoted to flood control purposes was 175,000 acre feet. The second study, made by engineers, provided 359,000 at the first dam, 560,000 at the second dam, 498,000 at the third dam, and there were two intermediate dams for which I have forgotten the figures. And they are not sure now that they have allowed enough, and neither am I. I fear, even under the best circumstances, a dual use of reservoirs.

In 1928 had our reservoir been in operation on the American River, had my office been responsible for its operation, we would have had a catastrophe. We were along in the middle of March, with two-thirds of the average rainfall, with no snow on the mountains, and the rivers down to nothing. If in charge of that reservoir one would have stored. On top of that we got a flood 50 per cent larger than the maximum ever heard of, and where would we have been with a fair engineer sitting at the head gates? Our community would have been under, for I would have stored water for power development, and any other sane engineer would have done the same thing. I fear the contribution to the power interests in connection with flood control. It may work all right in New England. I doubt if it can work with partial control of a stream in the West.

We are now planning on the Sacramento River a dam 450 feet high. How many acre feet will be behind it I cannot tell you. It is supposed to be a better regulator than the Colorado River Dam. Three seasons' storage, etc., and the flow of the Sacramento at that point is 276,000 second feet. That point is 100 miles above the city of Sacramento, the capital of the State. The run-off we figure between 30 and 50 second feet per square mile. Even with that regulation at Sacramento, in case of normal high seasons, you never know how the reservoir will be affected, because so much other water comes in.

I fear that the opportunity for co-operation between the power interests and the flood control interests in the Sacramento Valley is not present today. It is not present for these reasons: (1) the time was when hydro-power was greatly sought after, and (2) time was when the power interests looked carefully at every potential water power development, and attempted to get control, as they should. Immense amounts of money have been put into regulating reservoirs for the purpose of controlling the streams. The base power was hydro-power. The stand-by power was steam power.

With oil at $1 a barrel, which is cheap oil, hydro-power was still cheaper than steam. This was until about three years ago. Those of you who are familiar with steam development in the last few years appreciate the economies brought about in the production of steam. I am told that at this time the steam engine has been improved so much that it can get as much steam out of 42 pounds of coal as heretofore it did from 100 pounds. That has upset the economic balance between hydro-power in our locality, and steam power. But we have another disturbing factor, namely, the conservation policies adopted by the State of California, which every engineer, of course, is strongly behind. One of those policies is in connection with the production of oil. The amount of gas which shall be allowed to escape shall be not more than a certain ratio, and wasting of the gas into the atmosphere has largely ceased. That has made it incumbent on oil interests to find a market for gas. So we have enormous systems of gas lines from the oil and gas fields to the centers of population, which, of course, are also the centers of oil and gas use, and we have ample production of steam, with the result that the industries are not in a position even to accept all the gas delivered in the quantities in which it is being delivered. The result is that the power companies, which are gas companies as well, have the by-product gas delivered at well cost at the steam plant. They are paying 6 or 7 cents a thousand cubic feet, which compares very favorably with 22-cent oil. Now if $1 oil had hydro-power on the run, and 22-cent oil becomes available, there is no question which mode of development will follow. I think in the West we will not have the co-operation of the power companies in financing dams for flood control for some time. The situation here may be different.

I note that here you, too, have been attempting to find a relationship between precipitation and elevation. We have been trying to find that too. Like you, we have been handicapped in the number of rainfall studies from which we can get information. To date we have not been able to place our information in satisfactory form so that we can get the good relationship which has been derived heretofore. We hope sometime that we will be able to do it in our new country. Our first data of quantity discharges of any of the rivers in California, continuous over a period of one year, date from 1904. The rating curves of the gaging stations at that time were rather limited in accuracy. For flood heights in many cases they are not much better now. For normal heights our gage height relationship, where we do not have the influence of backwater, is very well established, and for total seasonal run-off we are very well informed. As to the relationship between the average and maximum flows we have only isolated observations. In twenty-five years the number of maximum discharges which have occurred, has not been large. Suppose we have two in twenty-five years, one on the twelfth and the other on the twenty-fifth year. Out there we have considerable argument as to whether we should use that particular point as representing once in twenty-five years or once in twelve and one-half years. Your probability run-off curve looks very different, whether you use it as one or the other.

Another thing — in our frequency curves the gage height discharge relation in a fixed channel where the velocity is sufficient is generally considered to be constant. For the same gage height you get the same discharge. On our streams, since we had the high water in 1904, I had a very short portion of the gage height discharge curve complete. That curve was produced as a tangent and was conservative, but we picked off the discharge of the American River for a certain gage height, and it was 98,000 second feet. In 1907 we had a few more points on the discharge curve, and when we got the same gage height the discharge was 120,000 second feet. In 1928 the discharge was 185,000 second feet. That is what the records show, gentlemen. "We have 98,000, 120,000 and 185,000 second feet." That is what the probability-frequency men say. The rest say, "We have had three floods in excess of 184,000 second feet." And the battle goes merrily on. Would that we had the same records as you. I looked at some. They are delightful. I hope their accuracy does not go the same way ours does.

J. H. KIMBALL, Member (by letter):* I have been very much interested in the work of the Committee on Floods which has contributed so greatly to the available data on flood flows. If I had felt able to contribute anything of value I should have been glad to have taken part in the discussion at the last meeting of the Boston Society of Civil Engineers.

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* Engineer, Metcalf & Eddy, Boston, Mass.

As the report has been printed and distributed it is probably too late to suggest any changes in it. If I had had an opportunity earlier I would have suggested some changes in the references made to the Miami conservancy district. In the tabulation given of the capacity of existing reservoirs, those of the conservancy district are stated to have capacities from 3,050 to 13,600 M. C. F. In the paragraph preceding this table it is stated that "One million cubic feet is equivalent to 11.6 cubic feet per second for one day, an absurdly small amount of storage considered from the flood point of view." The capacities as given in the table are misleading, as the storms which can be controlled by the reservoirs are much greater than might be inferred from these capacities. In some notes which I prepared for the December, 1928, JOURNAL of the Society there is included a table showing the magnitude of the storms which the conservancy reservoirs are able to regulate.

Of these five reservoirs, by the way, only one is on the Miami River. The Englewood Reservoir is on the Stillwater River, the Huffman Reservoir is on the Mad River, the Lockington Reservoir is on Loramie Creek, and the Germantown Reservoir is on Twin Creek, all of which are tributaries of the Miami River.

I was much interested in the remarks contributed by Mr. Gross, particularly those relating to the combined use of reservoirs for power and flood protection. It is undoubtedly true that in most cases a power reservoir will have unused capacity at times of storm, and will be able to regulate somewhat the floods below, but it is also true that the combination of conditions may be such as to produce a full reservoir before the critical storm occurs. This was exactly the case at the time of the flood causing the catastrophe at Dayton and other cities of the Miami Valley in March, 1913. A heavy storm in January of that year and rains in March previous to flood storms had exhausted the capacity of the drainage area for water storage.

Much fear of the Miami conservancy reservoirs was expressed on the ground that they would be devoted at some future time to power purposes. It is probable that many years may pass before these reservoirs are filled to an amount approaching their capacity. It seems probable, therefore, that the use of a portion of the reservoir capacities for power purposes may be suggested in the future. Having this in mind, the directors of the district placed a monument at each dam, with the inscription, "The dams of the Miami conservancy district are for flood protection purposes. Their use for power development or for storage would be a menace to the cities below." It is essential that the people whose safety is dependent upon the sufficiency of flood protection works should not labor under any delusion in regard to the degree of protection afforded. This has been well stated by Alvord and Burdick in their book, "Relief from Floods," page 54: "Anything less than to adequately protect a place of human habitation is worse than no protection at all, for it creates a false sense of security and multiplies the consequences of failure."

I have been much concerned in regard to the formula proposed in the Committee's report. It is true that its limitations are pointed out and the large range of values suggested for the two factors "C" and "R" should lead an engineer to study conditions carefully before applying the formula to any individual case. Similar formulæ have been copied in textbooks and handbooks, with a brief statement of average or probable values of coefficients. In this way they have become available for use by engineers and officials who are not familiar with their use and do not realize the importance of careful study of conditions in the individual case.

I was connected with the Miami conservancy district for ten years, serving from the period of preliminary plans to the completion of construction, being assistant chief engineer the last few years. I came to learn of the conditions through which the residents of the Miami River Valley passed, and came to have a very definite sense of the responsibility of the flood protection engineer in providing for the safety of lives and property. It is for this reason that I am fearful of the consequences of publishing a formula which may prove to be a dangerous instrument in the hands of an inexperienced workman.

ROBERT E. HORTON (by letter):* The technical literature on the New England flood of November, 1927, includes mainly the following papers:

1. Goodnough, X. H.: Rainfall in New England during the Storm of November 3–4, 1927. Journal of the New England Water Works Association, June, 1928, pp. 150–187.
2. Webber and Brooks: The Weather Map Story of the Flooding Rainstorm of New England and Adjoining Regions, November 3–4, 1927. Journal of the New England Water Works Association, March, 1928, pp. 91–103.
3. Kinnison, H. B.: The New England Flood of November, 1927. United States Geological Survey, Water Supply Paper 636–C, Washington, 1929.
4. American Railway Engineering Association. Report of Special Committee, New England Flood, November, 1927. Bulletin of American Railway Engineering Association, Vol. 30, August, 1928, pp. 3–105.
5. Report of the Committee on Floods, Boston Society of Civil Engineers. Journal of the Boston Society of Civil Engineers, September, 1930, pp. 290–464.

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* Consulting Hydraulic Engineer, Voorheesville, N. Y.

The last publication, which is here under discussion, comprises two main features:

1. A compilation of data with reference to the great New England flood of November, 1927. Many of these data had already appeared in the preceding papers.

2. An attempt to deduce a formula for computing the peak flood discharge of streams from the total flood run-off, excluding the base run-off which would have occurred had the flood not been superposed on the stream.

There are few great floods for which peak discharge rates are available at so many locations, and fewer still for which there are so numerous and complete data of rainfall on the tributary drainage basins.

The data of the flood of November, 1927, afforded an opportunity to do two important things:

1. To correlate flood discharge with the principal physiographic factors other than mere area of drainage basin, such as land surface slope, stream slope, drainage density, vegetational cover, and character of soil. Topographic maps, forest and soil maps, are available for much of the area affected by this flood. The physiographic factors described could all be determined quantitatively and expressed numerically for areas for which topographic maps exist.*

2. This flood also afforded an unusual opportunity to determine the relation of flood rainfall to peak run-off. Neither of these things has been done by the Committee.

It appears that in their zeal to eliminate the use of rainfall and physiographic characteristics from flood discharge estimates the Committee has missed its greatest opportunity. The writer does not wish to deprecate the value of the basic data published. The report of the Committee and the other papers referred to constitute a mine of valuable information which will yet prove useful in a variety of ways.

Reverting to the flood formula of the Committee, the use of flood run-off instead of flood rainfall is claimed as the main advantage of this formula. This, however, amounts to the substitution of an independent variable R, that is generally unknown in cases where there is any need of application of a flood formula, in place of the rainfall P, which is generally capable of approximate determination, at least.

Table 4 of the report gives peak discharges in the flood of November, 1927, at 134 locations. The question may properly be asked, At how many of these 134 locations could the peak discharge be reliably determined from data available even now, excluding rainfall, by the use of the Committee's formula? Evidently there are not many of these locations where this could be done, since the Committee has given flood graphs, which are a necessary prerequisite, for only about a dozen locations.

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* Methods for determining these factors have been given by the writer, Proceedings, American Society of Civil Engineers, Vol. 89, 1928, pp. 1081–1087. It may be noted, however, that in the formula there given for S_g, the ratio $\frac{L}{N}$ should be inverted to read $\frac{N}{L}$.

Even these few flood graphs — presumably all that were available — are a valuable contribution to the data of hydrology. The writer wishes to emphasize rather than to belittle the importance of flood graphs. They serve not only as a key to unlock the secrets of flood hydrology, but are also valuable in relation to storage and conservation, since most of the water which refills storage reservoirs comes from freshets, large or small.*

The use of rainfall data in estimating flood discharge is not usually a matter of choice but of necessity. To disregard rainfall data where other data are insufficient, as in most of the 134 cases listed, is a failure to make the best possible use of all the available information.

Instead of a formula for computing floods, it appears to the writer that the net result of the Committee's labors is an attempt to establish a relation between total flood run-off and peak discharge rate. Obviously the determination of this ratio and the publication of the data in as many cases as possible, together with data as to the attendant conditions, — rainfall distribution and physiographic factors for the drainage basins involved, — is a matter of great hydrologic importance. Unfortunately there are only about a dozen instances in the Committee's report where both the peak run-off and flood run-off depth are given (Table 28, pp. 400–401).† In these instances neither the flood rainfall nor the physiographic characteristics of the drainage basins are given. The data of Table 28 seem to have been chiefly relied on in the derivation of the formula, and the preceding statement seems, therefore, necessary as indicating the possible limitations of its applicability. Presumably the dozen instances referred to represent all of those out of the total of 134 cases for which both flood graphs and flood run-off could be determined. This illustrates the fact that in the majority of cases where peak run-off data are not directly available, they must be determined without the assistance of flood graphs. This at once suggests the desirability of devising methods of estimating total flood run-off from total flood rainfall; also it is desirable to extend the effort outlined in the report to determine the ratio of peak run-off to flood run-off in terms of physiographic factors. Going from flood rainfall to flood run-off and from flood run-off to peak run-off may easily give more reliable results than the customary method of going directly from flood rainfall to peak run-off. Flood run-off as defined by the Committee is mainly direct surface run-off. Direct surface run-off represents the net rainfall reaching the ground minus the infiltration. Evaporation from the soil and transpiration may be neglected as both come out of the infiltration. The net rainfall reaching the ground is the total rainfall less the amount intercepted by trees and other vegetation. This can be approximately determined if rain intensity and duration are known. The total deduction from gross rainfall to obtain flood run-off is therefore equal to interception plus infiltration. Table 14 of the report (pp. 351–354) gives numerous examples of flood rainfall, deduction and resulting flood run-off. In these tables the total deduction is defined as "retention," following the practice of the Miami conservancy district. The writer does not use the term "retention" in this connection, for two reasons:

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* About thirty years ago, when engaged in stream gaging work, the writer adopted the policy of publishing flood graphs wherever available. The United States Geological Survey probably has data of hundreds of flood graphs unpublished. Published data of average daily discharge during flood periods do not in general suffice to determine accurately either the time of occurrence or magnitude of the peak.

† Many additional data of total run-off (million cubic feet) in the November, 1927, flood are given in Table 4, pp. 310–311, but do not seem to have been used in deriving or checking the formula.

1. Part of the deduction, namely, interception, is neither retained nor appreciably detained, but is returned directly to the atmosphere as water vapor, without reaching the ground.

2. Infiltration does not represent *retention*, but merely represents temporary *detention*.

In Table 14 the rainfall duration is not given, but the dates covered by the different storms are given. The most probable duration of the storm is obviously one day less than the total number of rainfall days, since the most probable time of beginning is about the middle of the first day, and the most probable time of ending, about the middle of the last rainfall day. Deducting one day from the number of rainfall days in each instance, and dividing the storm rainfall and total deduction each by the resulting approximate rainfall duration in days, gives for each storm a series of values representing approximately the average rainfall per day and the average deduction to be made per day for interception and infiltration. While there may be a number of errors in the rainfall duration so obtained, yet, when the resulting values are plotted, it appears that there is a fairly consistent relation between the total rainfall and the amount to be deducted therefrom in order to obtain the flood run-off in the case of each of the streams for which data are given in Table 14. These relations are given below:*

Murchison Farm Brook	$D_1=0.64\ P_1$
Wachusett drainage basin	$D_1=0.70\ P_1$
Ware River at Gibbs	$D_1=0.76\ P_1$
Middle Branch, Westfield River	$D_1=0.54\ P_1$
Swift River at West Ware	$D_1=0.66\ P_1$
Westfield River at Westfield	$D_1=0.62\ P_1$

It is not to be assumed that the rule of simple proportionality indicated by these figures is exact, but the closeness of the relationship indicates the possibility of determining total flood run-off with a good degree of accuracy for a given basin from the flood rainfall. If P_g is the net rainfall reaching the ground after deducting interception, and the infiltration rate on the area is F, then when the rain intensity is less than F practically all of the rain will go into the soil, while if the rain intensity is greater than F, infiltration will take place at the rate F, and the excess rainfall during such periods of intensity exceeding F will constitute the direct surface run-off. If, therefore, the excess rainfall is proportional to the total rainfall, then the flood run-off should also be proportional to the total rainfall.

The report states (page 382): "If the concentration period has been reached, the unit run-off equals rate of rainfall." However (page 395), the report apparently recognizes the necessity of deduction for infiltration in determining the flood run-off. In applying the formula to maximum floods it is not clear that any distinction has been made between flood rainfall and flood run-off.

Although discarding rainfall as a basis of estimating either flood run-off or peak discharge, the report apparently relies entirely on rainfall data as a basis of determining flood frequency.

There is a limit to the flood-producing capacity of a given drainage basin, although the report does not seem to recognize this limit in the formula given on page 344. Referring to the formula for flood rainfall there given, it may be noted that P is expressed as being proportional to $F^{.27}$, where F is the frequency in years of the rainfall, P. It has been repeatedly shown that rainfall frequency is not a simple power function such as that here used, although it is capable of representation by such a function over a limited range. Great danger lies in extending such an empirical rule beyond the limits of the data.

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* Excepting the Miami, most of the data for which are for storms of less than the concentration period.

The report seems to recognize the maximum limitation of rainfall and floods in the statements (page 399): "The maximum flood run-off, *R*, is probably not over 8 inches;" and (page 406): "The recommended values for the [flood] run-off in inches, *R*, are as follows: . . . For maximum flood, 8 inches (200 years and upwards)." The formula for the flood rainfall *P*, given on page 344, immediately becomes transformed by some magical process into a formula for *R*, the flood rainfall. Unless this is a misprint it amounts to the assumption that the maximum flood run-off is equal to the maximum flood rainfall. Taking the flood rainfall as given in Table 9 for $T=24$ hours and for a frequency of 10 years, the amount is 4.40 inches. Applying the formula given on page 344, the flood rainfall to be expected with different frequencies, on this basis, is as follows:

	Inches
10 years	4.40
100 years	8.18
1,000 years	15.26
10,000 years	28.42
100,000 years	52.00

In other words, the formula and table recognize no finite limit for the amount of rainfall on any drainage basin.

The statement above quoted, that the maximum flood run-off to be expected on a drainage basin of any size is 8 inches, is interesting if true. To be true this statement requires that the increase in flood run-off duration on large areas must precisely balance the increase in flood run-off intensity on smaller drainage basins.

The assumption that $R=P$ for great floods, which seems to be the basis for the formula for *R* on page 344, is controverted by the data given in Table 14, already cited.

Attention is given in the report to the question of run-off from melting snow. The real fact to be determined is the amount of snow run-off which will be produced by a 1°-day temperature excess above 32° F. The writer does not believe this fact can be reliably determined by the method of analysis used in the report. It is assumed that the amount of snow converted into water and delivered to the stream is directly proportional to the excess of the *mean* daily temperature above 27.1°. Two conditions may exist during a period of snow melting:

1. The temperature may be above 32° throughout the day. In this case the effective temperature is directly proportional to the excess above 32°, and is not proportional to the excess above 27.1°.

2. The temperature may be alternately above or below 32°, in which

case melting takes place as the result only of the excess temperature in degree-hours above 32°. This excess temperature may, however, produce little or no run-off from a thick layer of snow. Snow is a good insulator. If the body of the snow is at a temperature slightly below 32°, the water resulting from melting which takes place at the surface will, for a time, be absorbed and withheld in the body of the snow or as a capillary layer at the bottom of the snow, producing no run-off whatever.

There is, however, another factor to be considered. During a period of snow melting, the sky may be cloudy and the temperature nearly uniform, or the sky may be clear and the temperature subject to a range of 10° or 15° or even more, from minimum to maximum. With a mean air temperature for the day of, say, 25° to 30°, there would be no melting whatever in the first instance, whereas in the second instance melting would occur during the period of excess temperature to an extent proportional to the temperature excess. Temperature range must therefore be considered, and the temperature excess above 32° rather than the mean temperature is really the controlling variable.

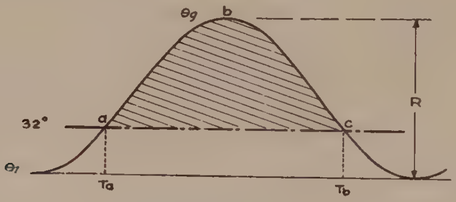

FIG. 1. — DETERMINATION OF TEMPERATURE EXCESS

For steady, fair weather conditions the diurnal temperature curve can be approximated by a sine curve (Fig. 1). Taking the origin at the minimum point, the equation of this curve is —

$$\theta - \theta_l = \frac{R}{2}\left\{ 1 + \sin \frac{\pi}{12} T - 6) \right\} \qquad (1)$$

where —

θ = actual temperature at the time, T.
T = time in hours from the epoch of minimum temperature.
θ_l = minimum temperature.
θ_g = maximum temperature.
R = diurnal temperature range = $\theta_g - \theta_l$

This equation can be integrated, giving the total temperature above the minimum, D_h, in degree-hours from the time of the minimum to any time, T:

$$D_h=\frac{R}{2}\cdot T-\frac{6\,R}{\pi}\left[\cos\frac{\pi}{12}(T-6)\right] \qquad (2)$$

Assuming that the minimum temperature is below and the maximum temperature above 32°, then the temperature excess in degree-hours is the area *abc* above the 32° line on Fig. 1. To determine this excess it is necessary, first, to determine the times T_a and T_b at which the temperature rises above 32°, and at which, after passing the maximum, it falls below 32°.

From equation (1) —

$$T_a=6+\frac{12}{\pi}\sin^{-1}\left\{\frac{2\,(32-\theta_l)}{(\theta_g-\theta_l)}-1\right\} \qquad (3)$$

Also, from the symmetry of the curve —

$$T_b=24-T_a \qquad (4)$$

The temperature excess equals the area under the curve between T_b and T_a less the area represented by the temperature below 32°, which is —

$$(32-\theta_l)\ (T_b-T_a) \qquad (5)$$

Also —

$$T_b-T_a=24-2\,T_a \qquad (6)$$

Substituting and reducing gives —

$$E_{32}=\left[\frac{R}{2}-(32-\theta_l)\right](24-2\,T_a)+\frac{12\,R}{\pi}\sin\frac{\pi}{12}T_a \qquad (7)$$

where E_{32} is the temperature excess in degree-hours above 32°. Computation by this formula for temperature ranges of 15° and 20° F., respectively, and with various minimum temperatures, gives the following results:

For $R=15°$—

θ_l =	20	25	30
E_{32} =	14	63	139 degree-hours.

and with $R=20°$—

θ_l =	20	25	30
E_{32} =	56	118	200 degree-hours.

It will be seen that the excess temperature available for the melting of snow increases very rapidly as the minimum temperature approaches 32°. If the mean temperature is used as the variable, then in cases where the temperature ranges alternately above and below freezing it appears certain that the amount of heat available for snow melting varies much more rapidly than is indicated by the assumption of direct proportionality to the temperature excess above 27.1°, used in the report. When and how much, if any, of the resulting water produced by the melting of snow will reach the streams depends on the detention by subsequent freezing and on the amount of capillary detention in the snow mass.*

There are various other matters in this report which deserve or require critical examination, particularly a comparison of the theoretical results as to the characteristics of the flood graph, with actual flood graphs derived from other floods in other localities. Until this has been done the writer hesitates either to accept or reject these theoretical considerations.

The expression "flood run-off" is used in the report with a special meaning. As used it excludes the run-off which would have occurred had there been no flood. It would seem that to avoid confusion the expression "net flood run-off" should be substituted in this instance, reserving the term "flood run-off" for its present and customary use, where it includes all of the run-off which occurs during the flood period. Data of total flood run-off or flood run-off in this sense are of great importance in determining spillway capacities, operation of storage reservoirs, etc., and their collection and publication should be encouraged. It is also desirable, as the report clearly shows, that additional data of net flood run-off should be collected and published.

Considerable variation is possible in determining the net flood run-off from the total flood run-off. A rough approximation to the net flood run-off can be obtained by deducting from the total flood run-off a quantity equal to the product of the rate of run-off at the beginning of the flood rise multiplied by the flood period. The deduction so obtained will always be too large. A more rational result can be obtained, where the data are available, by selecting, from previous records, a period at least equal to the period of flood run-off, where the initial flow equals that at the beginning of the flood rise and where there is no addition to the stream from rainfall or melting snow during the

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* The phenomena of melting of snow and a laboratory determination of the constant, or amount of snow melted per degree-day of excess temperature, were investigated by the writer a number of years ago (Monthly Weather Review, December, 1915, pp. 599–605). The conclusions there given have been confirmed in a large measure by other investigators.

period. The area under a segment of the hydrograph for such a period will represent very nearly the true deduction from the total run-off in the given flood.

JACOB A. HARMAN (by letter):* The report of the Committee on Floods in New England recently presented to the Boston Society of Civil Engineers by the Committee is a splendid example of co-operative engineering study which will doubtless have far-reaching effects upon future flood studies, as it brings out new methods of investigation with illustrations of sufficient scope to lend weight and assurance to the value of the methods therein developed and illustrated.

In studying plans for flood control of the Illinois River (1928), the writer was confronted with large numbers of discharge measurements which had been taken at intervals during a period of thirty years covering practically all stages of the river at each of several stations. Many of these discharge measurements showed such divergence from the average rating curve that it was considered necessary to investigate the causes. The discharge measurements were made by the United States Geological Survey, the United States Engineer Corps, the Engineers of the Sanitary District of Chicago, and some by engineers in private practice, including the writer, covering flood stages and low stages at Peoria before diversion from Lake Michigan through the Chicago Sanitary and Ship Canal. These measured discharges were frequently 25 per cent or more from an average rating curve, but they could not be discarded as due to errors of observation.

Several years ago, when the writer was making studies for flood control of tributary streams in the backwater area of the Mississippi River, it was necessary to estimate the stage in the tributary streams for discharges under backwater conditions. It was fortunate that river stage readings at three points on one of the tributary streams were available for a number of years covering high water in the tributary, both with and without backwater from the Mississippi River. A series of rating curves or stage-slope-discharge diagrams, based upon the fall between the gaging station and the gage either above or below, was found to satisfy the conditions of flow.

A thorough study was made of discharge measurements and slope relations on the Illinois River, and we were able to reconcile all but a few of the discharge measurements to within a working range.

The Illinois River presented an unusual opportunity for a study of this character. From Starved Rock, above La Salle, Ill., to Grafton at the mouth, the normal fall is only about 25 feet in 230 miles, and the

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Mississippi backwater effect extends up the Illinois River the entire distance.

The gaging stations on the Illinois River are located at bridges where the flood sections are greatly reduced. These "narrows" have the effect of wiers, with increased velocity through and below the gaging station. The discharge may be modified by (1) backwater from the Mississippi River, (2) backwater from the flood-flow of the tributaries entering below gaging station, (3) increase in slope of the river above the gaging station by the flood waters from tributaries, and last, but nevertheless of great importance, (4) the construction of levees for reclaiming agricultural land, greatly reducing the storage and flowage space in the valley.

Daily stages have been recorded at a number of the stations on the Illinois River for many years. Using these daily stages for the slope at the gaging station on the day when the discharge measurements were made, it was found that either the upstream or downstream slope would reconcile the discharge measurements, and stage-slope-discharge rating diagrams were prepared for a number of stations, as shown on pages 157 and 158 in the "Flood Control Report" of the Division of Waterways of the State of Illinois, 1929, a copy of which is presented to the Boston Society with the compliments of the writer.

At the writer's request, the engineers of the sanitary district of Chicago in 1929 made a large number of discharge measurements through rising and falling stages of the flood period on the Illinois River at three points where daily gage readings have been recorded for many years. These discharge measurements were made with special care, and frequently the velocities were taken at all depths. Vertical velocity curves have been plotted and the discharge measurements computed with more than the usual care. This series of discharge measurements has more than justified the accuracy of this method, notwithstanding the fact that the fall is very slight and the daily stage readings are taken by ordinary observers. The great distance between gages gives an accuracy of the slope which could not be obtained even by the use of hook gage methods for short reaches.

In the study of the Illinois River, it was found that by using the Manning formula, a constant value of "n" for the channel ($n=0.024$) and values of "n" for the overbanks section ($n=0.080$ to $n=0.110$), it was possible to reproduce the flood crest profiles of the Illinois River from La Salle to Grafton, 230 miles, for a number of floods, varying several feet in stages, with slight variations from the observed stages, except where the overbanks floodway was modified by the construction or breaking of levees, and these differences were reconciled when the changed conditions were applied. In the overflow section the same value "*n*" was used in each reach for all flood stages. To obtain the same results, using the Cutter formula for "*n*", the values of "*n*" ranged from 0.027 to 0.040 for the channel, and from 0.105 to 0.126 for overbanks, as shown on page 96 of the Illinois River Report, above referred to, the greater variation in the value of "*n*" being where flatter slopes were encountered.

ADOLPH F. MEYER (by letter):* It is not possible for me to send you a discussion of the interesting and instructive Flood Report prepared by your Committee. I desire merely to call your attention to the fact that the engineer who originally proposed the run-off formula which used the square root of the area as a factor is "Myers." I believe his initials are E. T. D., as given on page 161 of the second edition of "Merriman's Civil Engineers Pocket Book."

My own run-off formula was first published in the 1922 report of Hon. E. V. Willard, Commissioner of Drainage and Waters, State of Minnesota. It also appears on page 369 of the 1928 edition of my "Elements of Hydrology." On page 373 the formula was applied to Mississippi River floods and Ohio River floods, and shows reasonably good agreement with observed discharges. My own studies led to the conclusion that the six-tenths power gave better results, particularly for Minnesota conditions, than the five-tenths power.

Please see that your Report is corrected so as to give Mr. Myers the credit for his formula.

One of the most interesting conclusions which I noted in the report of your Committee is to the effect that large expenditures for flood protection works were not warranted by Vermont conditions, but that it is highly desirable to combine water-power and flood-control reservoirs.

C. S. JARVIS (by letter):† To one who was permitted to observe the effects of the New England flood of November, 1927, before the streams had resumed normal stage, the report of the Committee on Floods has a special interest. Among the scenes of havoc wrought in the stricken valleys it was difficult to conceive anything like a scientific analysis or an orderly treatment of the phenomena which gave rise to the disaster. However, the determined and methodical manner in which the surviving residents proceeded to place their homes in order, or to recover whatever was available as salvage, the prompt relief afforded under the direction of the Red Cross, the Department of Commerce, the War

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Department, and auxiliary organizations, and by neighbors, all seemed to have this one message: "Why be discouraged?" — the text of a ringing appeal delivered publicly within a week after the catastrophe. The same outlook seems to have actuated the Committee on Floods in their painstaking research.

It is remarkable with what ease formulæ may be derived involving arbitrary constants and specific functions of variables; likewise the ease with which either the length, breadth, square root, or other function of drainage area may constitute a principal variable, measuring the influence of watershed area. The remarkable assumptions that are made for the sake of simplicity, such as in Fig. 15, where the time of rise and recession of flood wave are assumed as equal, or that the precipitation continues at a constant rate throughout a given period, or that 100 per cent run-off may occur from an extensive drainage area, or that precipitation prolonged beyond the time of concentration will make no difference in the maximum rate of run-off — all probably differ from the actual happenings more widely than the several best standard formulæ would differ among themselves if wisely applied within their proper range. In spite of all the travail attending the birth of ideas, it is encouraging to see what a logical, comprehensive and adaptable flood formula has been derived.

It seems proper to remark that the 100 per cent on the Myers scale was chosen by the writer to represent about the attainable limit of flood intensity. During subsequent studies he encountered isolated cases that ran somewhat higher, notably, the Ardèche River, France, 110.2 per cent; Musi River, Hyderabad, India, 144.6 per cent; Santa Catarina River, Monterey, Mexico, 100.8 per cent; Salado Creek, Salado, Texas, 117.5 per cent ("Flood Flow Characteristics," Transactions, American Society of Civil Engineers, Vol. 89, p. 985).

If the formula derived by the Committee on Floods rates as high as 80 per cent on the Myers scale, as it appears from Fig. 19 and page 405 of their report, then the writer must express the opinion that they have chosen a limit somewhat beyond the probable intensity of natural run-off in New England, even if the frequency be rated at a century or longer period. In other words, to express what seems to be a century maximum for New England, C_F equal to 1,000 and flood run-off of 6 inches depth on watershed according to the Committee's Formula 15, or a rating of 60 per cent on the Myers scale, would be the writer's choice after a limited investigation both along New England rivers and in technical literature. It is reassuring, however, to find large factors of safety advocated to represent conditions well beyond the attainable.

The profession is doubly indebted to the Committee and to the Boston Society of Civil Engineers for their comprehensive and illuminating report.

W. P. Creager (by letter):* The Boston Society of Civil Engineers is to be congratulated that it can obtain from its membership a committee with sufficient interest, energy and ability to present a report which evidently required an immense amount of labor, and which contains a wealth of valuable information and conclusions regarding the recent New England flood in particular and flood characteristics in general.

The writer is particularly interested in that part of the report dealing with "The Influence of Size and Distribution of Drainage Areas upon Flood Flows," starting on page 365 of the report.

In this section it is stated: "Hence, the conclusion can be drawn that for identical storms (within the concentration period) on similarly shaped watersheds having the same velocities and negligible pondage, the peak flows will vary directly with the square root of the drainage area."

The writer will attempt to show that (1) this statement is not correct "for identical storms," and (2) nevertheless, for exactly similar drainage areas having the same rainfall characteristics, floods of equal frequency will vary directly with the square root of the drainage area.

The fallacy in the Committee's deductions lies in the following statements on page 366: (1) "For storms of longer duration the flow will depend upon the greatest average width of the drainage basin for such a distance as is covered by the flow of water during the assumed period of the storm." (2) ". . . the corresponding widths would vary directly with the square root of the drainage areas."

The first statement is evidently correct (for identical storms). If the word "width" in the second statement is intended to mean "the greatest average width," and this is necessarily true to follow the Committee's reasoning, the second statement is not correct.

For the Committee's Watershed C and a 20-hour storm, the maximum average width is W–12.5, where W is the total width. For a width W of 50 miles, the maximum average width is 37.5 miles. For a similarly shaped watershed of four times the area ($W = 100$ miles) and the same storm, the maximum average width is 87.5 miles, or two and one-third times as wide, instead of twice as wide as would be required if it varied as the square root of the area.

This error does not apply to the Committee's rectangular drainage areas.

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* Vice-President and Chief Engineer, the Power Corporation of New York, Watertown, N. Y.

In order to show the actual variation of floods with drainage areas, under the Committee's assumptions, Figs. 2, 3 and 4 have been prepared.

The Committee's 20-hour storm and 2.5 miles per hour flow were adopted. However, the "time required for flow from the outer edges of the (square) drainage area to the thread of the stream" was not neglected.

Three types of drainage areas have been assumed as indicated in the figures. In each case the route of the run-off is indicated by arrows. Type I, shown in Fig. 2, is identical with the Committee's square area.

Curves A in these figures indicate the results for "identical storms." It will be noted from the equation for curve A of Type I area, that the flood does vary as the square root of the drainage area above point "*b*" (this area corresponding to the limit of concentration period). This is because, as stated before, the error does not apply to rectangular areas, and "feather type flow."

The dotted line in Fig. 2 corresponds to the Committee's neglect of the time required for flow from the outer edges of the drainage area to the thread of the stream.

Referring to curves A for the other two areas it is seen that the flood decidedly does not vary directly as the square root of the drainage area, the equations being generally of the type —

$$Q = C\sqrt{A} - K$$

We now come to the case of the variation of floods of equal frequency with drainage area. For this case, two corrections are necessary.

First, it is quite evident that if a 20-hour storm results in a flood of a given frequency on a given drainage area it will give a storm of a much less frequency on a much smaller area. In Mead's "Hydrology" is given a curve* showing the relative rates of rainfall in terms of the 24-hour rate, based on equal frequency. From this curve it is possible to calculate the duration of the rainfall which will produce the maximum flood of a given frequency for any size of drainage area. This correction results in curve B in the three figures.

The writer was very careful to make the calculations as exact as possible. The actual points calculated are shown by circles on the figures. It is very surprising to note that the resulting equation for all three types of drainage areas took the form —

$$Q = C\,A^{0.6}$$

The curves from the three equations passed through the calculated points with surprising exactness from zero flow to the end of the diagram.

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* Reproduced as Fig. 4 in the writer's "Hydro-Electric Handbook."

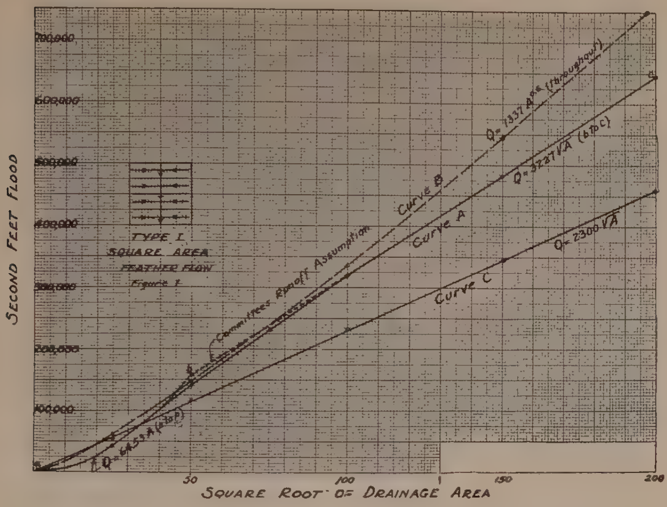

FIG. 2

(Discussion by W. P. Creager)

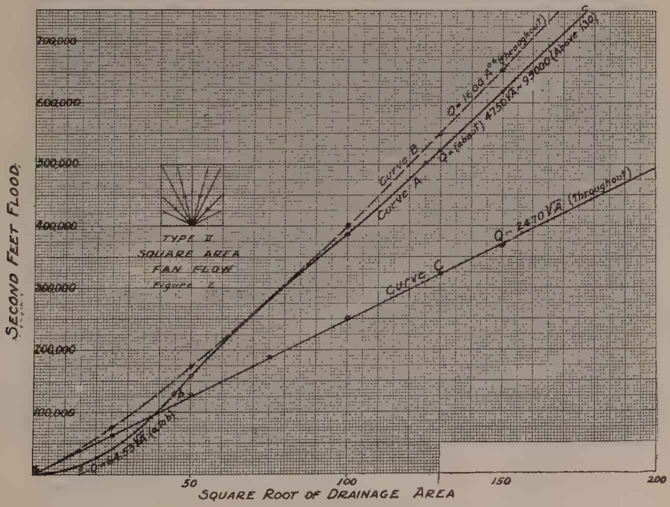

FIG. 3

(Discussion by W. P. Creager)

The second correction is based on the fact that average rainfall intensities of equal frequency become smaller as the drainage area increases. The writer's chart, showing the probable rainfall intensities over large areas in terms of rainfall at a single station, is indicated in Fig. 14 of the writer's "Hydro-Electric Handbook." Making the necessary correction from this chart results in the C curves in the three figures. Again, it is quite surprising to note that the resulting points lie almost exactly on curves having the form —

$$Q = C\sqrt{A}$$

This is the writer's final form of the equation showing the variation of floods of equal frequency with drainage area.

It is interesting to note, in passing, that the expected flood from a semicircular, fan-flow drainage basin, similar to Type III, Fig. 4, is 1.76 times that which might be expected from a square, feather flow drainage basin similar to Type I, Fig. 2, of the same area.

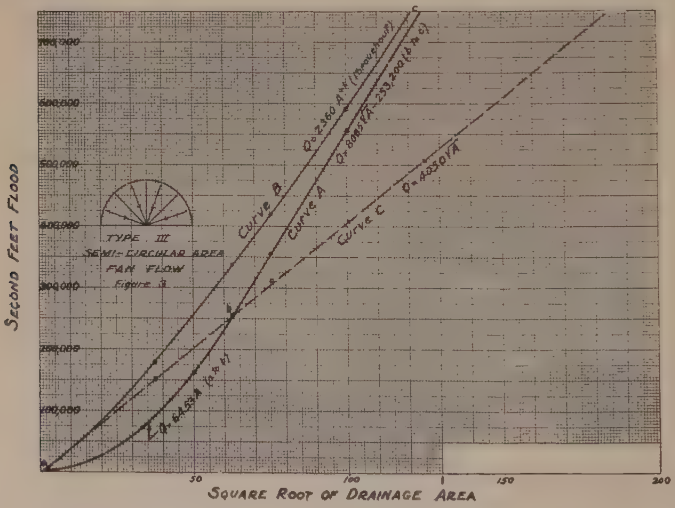

FIG. 4
(Discussion by W. P. Creager)

R. W. DAVENPORT (by letter):* "The steady elimination of our economic wastes" is a social policy which in recent years has been commended to us by high authority and which it may be hoped is becoming more and more generally accepted and applied. Among the numerous forms of economic waste which may well be considered, surely not many are more devastating of human wealth and happiness and more generally deplorable than those incident to losses from floods. Contemporaneous with increased attention in the direction of general elimination of wastes, there may have been some quickening of interest, thought and action in the elimination of economic flood losses. However this may be, engineers will agree, unquestionably, that great public benefits may be derived from a thorough, orderly study of, and protection against, floods, and that up to the present, measured relatively, only a beginning has been made toward the desired end. The problems involved are largely of an engineering nature and have several aspects, important ones being the planning and constructing of flood control works and the location of industrial and other works and structures along stream channels and on flood plains with due regard to unjustifiable encroachments. Authentic information regarding the stage, discharge and frequency of the floods of a river in readily usable form is highly important to the execution of such work.

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* Senior Hydraulic Engineer, United States Geological Survey.

The report of the Committee on Floods presents a compilation of information on floods in New England, and particularly an interesting account of the flood of November, 1927, which should be of great value to engineers of New England in considering protection against floods and in planning works which may be affected by them. Especially noteworthy features of the report are the analytical studies of certain flood flow factors, and the progress made toward clarification, in some part at least, of the fogs of complexity and confusion which prevent clear perception of the behavior of these factors. Development and dissemination among engineers in this manner, of knowledge which will aid in providing for floods more intelligently, have value which, although difficult to appraise, is undoubtedly very high. The report is highly satisfactory to the critical student of hydrology in its thoroughness and in its breadth of comprehension. The Committee is to be congratulated on its contribution to the scientific knowledge of floods.

It is possible that the proposal of a new formula for flood discharge may not have the undivided sympathy of all engineers. Several such formulas have been presented, usually by individuals on a basis of studies considerably localized in scope and containing factors and coefficients which reflect more or less predominantly the special conditions of the locality and the ingenuity of the particular investigator. The accounts of such studies are instructive and decidedly worth while. However, in making a survey of such studies there is perhaps justification for feeling that notwithstanding their substantial contribution to this field of knowledge, there yet remains to be made a thorough comprehensive study of flood phenomena which shall start from the common foundation and afford a satisfactory determination of fundamental terms or denominators. Reflection on the tendency to blind faith in the efficacy of a formula by many users is an incentive to precaution in the manner in which a new formula is suggested for general use. The Committee is undoubtedly wise in specifying that the formula it derives is "a general formula for New England." The following statement of the Committee, quoted from page 299 of the report, is especially significant and may well be emphasized:

> In presenting these formulæ the Committee would emphasize the fact that the flood situation at any point on any stream presents a problem of its own. No general formula can be of universal application. It is only by special study of the conditions at the particular point under consideration that the best results can be obtained. The flood hydrographs of previous floods, when studied in connection with the nature and type of the storms producing these floods, are believed to afford the best information for solving the problem.

The Committee recommends that floods be classified in relation to flood run-off depth in inches over the drainage area. This is a logical path of approach to the study of flood flows because it brackets for individual consideration an important criterion which, although not independent of other factors, is well suited to separate study. There is, of course, a rather wide range of latitude in the possible constitution of a given flood run-off from a drainage area, and in a study of a particular stream, ample consideration should be given to this possibility and its effects on the results. In correlating results for different rivers it is shown that some order may be attained by narrowing consideration to those floods caused by rainfall limited somewhat closely to the concentration periods of the basins. Viewed in a general way, there would still appear to be considerable opportunity for diversity of results after this limitation.

Assuming that the coefficient C_F, the measure of the flood producing characteristics of the drainage area, is a constant for a given drainage basin, the form of the proposed formula indicates that the element of frequency of the particular flood considered must be cared for by the value selected for R, the flood run-off in inches. If it is desired to determine the flood discharge likely to be equaled or exceeded once in one hundred years it becomes necessary, evidently, to determine the value of R for the given drainage area likely to be equalled or exceeded once in one hundred years. This apparently involves consideration of several factors: the concentration period of the particular basin, rainfall frequency data, the part of the rainfall that would go into run-off, climatic characteristics which might influence the application of the method, etc. — all being subject to a measure of uncertainty which seemingly would be reflected in increased degree in the final value of R. The writer suggests that, although the information on these various factors may seem reasonably satisfactory, it may often be desirable, if additional assurance of reliability is desired in connection with an economic study requiring consideration of frequency, to make an independent approach by one or more of the various statistical devices which have been applied to engineering studies in recent years. A specific example of what the writer has in mind is indicated hereinafter in relation to the comments on the data of the Kennebec and Penobscot rivers.

A fundamental conception of the constitution of stream flow which is becoming increasingly satisfying to students of hydrology is that the flow of a stream at a given time represents the culmination of a multitude of conditions, meteorologic, climatic, topographic, geologic, etc., which conditions are subject to combine more or less fortuitously and in infinite variety to produce flows of different magnitude. These conditions, some independent and some interdependent, may behave favorably or unfavorably to the production of high flow, and when the combination or sequence of conditions is predominantly favorable, the result is a high flow. The familiar discharge-duration curve shows that the more predominantly favorable such combination of conditions, the less frequent is the occurrence, the gradation apparently following some law which may have its basis in the essential characteristics of the particular drainage basin. The unusual flood is caused, of course, by the extraordinarily favorable combination of these fundamental conditions. In a sense, a study of floods may be regarded as having to do with those phenomena of stream flow represented by the extension of the duration curve through the portions well defined by observed data to the portions less well defined. It is often profitable in such studies to correlate the less frequent flood flows with the more frequent high flows, and this procedure is familiar in the various types of analysis of the discharge-frequency relations of flood flow series.

The writer has made application of such a device in a more or less superficial analysis of the stream-flow data of the Penobscot River at West Enfield and Kennebec River at Waterville, these being two of the streams considered by the Committee. The periods considered on both streams were the years 1902 to 1926, inclusive. The following table shows the recorded mean daily discharge on each of the two streams on the fifth, tenth, and other multiples of five up to the sixtieth, highest days, and the ratio of the Kennebec discharge to that of the corresponding Penobscot discharge:

Order of Magnitude of Daily Discharge Shown	Penobscot River, West Enfield (c. f. s.)	Kennebec River, Waterville (c. f. s.)	Ratio of Kennebec River to Penobscot River
5	93,400	78,800	.845
10	84,200	61,000	.725
15	73,700	54,300	.737
20	70,300	51,100	.729
25	68,700	47,870	.695
30	65,600	46,570	.710
35	63,100	45,400	.719
40	61,200	44,500	.726
45	60,400	43,400	.719
50	59,400	41,700	.702
55	58,400	41,000	.703
60	58,000	40,000	.690

It would, perhaps, be anticipated, in the light of our knowledge of stream flow, that for two streams assumed to be of similar characteristics in all respects except size, a series like that shown above of ratios between discharges of equal frequency would show a gradual increase as the discharges increased, from a ratio approximating the ratio of the two drainage areas for intermediate magnitudes to a ratio approximating the square root of the ratios of their drainage areas for more extreme flood flows. If the conditions of the two drainage basins were such as to tend to produce medium flows proportional to their areas, but the smaller basin had characteristics more conducive to rapid concentration than the larger basin, it is likely that as the discharges increased, the ratio would be found to vary from approximately that of the two drainage areas for intermediate magnitudes to a value somewhat larger than that of the square root of the ratios of the drainage areas for more extreme flood flows.

The ratio of the Kennebec drainage area to that of the Penobscot is practically 0.64 considered either as to total areas or to uncontrolled areas, and the square root of the ratio would be 0.80. In view of the previous discussion it is interesting to note that the computed ratios have values over the range of discharges shown, rather uniformly close to 0.7, except the ratio of 0.845 for the fifth highest day, which may be based on too few observations to make it reliably representative. The ratio of the average run-off of the two drainage basins is close to 0.60, or slightly less than the ratio of the drainage areas. One is perhaps warranted in concluding that these data indicate that the more frequent floods approximate 0.8, the square root of the ratio of the drainage areas, sufficiently closely to indicate that the flood-producing characteristics of the two streams as respects floods of the magnitude of the mean daily flood flows shown, are not materially different.

It is appreciated that in considering the part of a duration curve representing the infrequent flows the point is reached where time intervals of less than a day must be used in order to assure proper definition. It is doubted, however, that this fact detracts from the general validity of the last conclusion.

The flood coefficients of 454 for the Penobscot and 907 for the Kennebec as shown in Table 22, page 391, correspond to run-offs of 3.02 and 3.12 inches, respectively. The data of Table 25, page 397, indicate that run-offs of 50-year frequency are nearly the same for areas from 4,000 to 8,000 square miles, which range includes the areas under consideration. It is inferred, therefore, that the above run-off values may be regarded as corresponding to approximately equal frequencies. The ratio between the floods given in Table 22 is 1.65, and corresponds to the ratios above discussed. It would seem that these values of 94,420 for the Penobscot, and 155,600 for the Kennebec, and their ratio of 1.65, should conform to the extension of the series shown herewith in the table of page 7.

Evidently the values of the Kennebec series would have to increase much more rapidly than those of the Penobscot series, and in a manner hardly prophesied by the available terms of the series, in order that values of the amounts given, and corresponding as respects frequency, may be reached. The characteristics of the two streams which would lead to such a relative result apparently are not reflected in the portion of the series shown.

As a matter of fact, there is basis for some doubt as to the validity of the comparison of flood characteristics of the two drainage basins on the basis of the September, 1909, flood for the Penobscot and the December, 1901, flood for the Kennebec, and in this may be the cause of the apparent discordance. The former flood was caused by a six-inch autumn rain covering three days and following a dry period (Water Supply Paper, 279, page 133), whereas the latter was caused by the combination of a thaw and warm rain of two or three inches over a period of two days, occurring with a ground covering of snow having a water equivalent of about five inches, and apparently followed immediately by a freeze-up (Water Supply Paper, 198, page 116). A similarly favorable liberation of surface water would conceivably have produced a higher run-off coefficient on the Penobscot if it had occurred there.

This example seems to emphasize the importance of broad consideration in flood flow studies, as advised by the Committee in the statement previously quoted.

The scientific knowledge of flood phenomena covers a broad field, and it is no disparagement of the valuable contribution of the Committee to apply the significant old expression that what we do not know would fill volumes. The Committee deserves praise for advancing such scientific knowledge, and it is confidently hoped that its report will inspire and quicken further studies of the subject.

ROBERT FOLLANSBEE (by letter):* Floods in the Rocky Mountain region (including the plains area adjacent to the front range) are of two types: (1) the floods on the larger streams due to general rains of several days' duration over comparatively large areas; and (2) the so-called cloudburst floods due to intense rains of short duration covering well-defined small areas. Floods of the first type are similar to those in the eastern part of the country, but are relatively infrequent in the Rocky Mountain region, whereas the cloudburst type, with its "veritable wall of water," is least known in the East, but is the common type in the West.

To determine the flood coefficient of a stream by means of the Committee's flood formula an approximate flood hydrograph is required. For the reason that the first type of flood is infrequent, but few hydrographs for severe floods are available in the central Rocky Mountain region. Although the cloudburst type is more frequent, the stream rises and falls so quickly with only a few minutes' peak flow, that without a recording gage no hydrograph is possible. However, within the past ten years, five floods, each the greatest known on its particular stream, have been studied and hydrographs prepared. Of these, the flood on Powder River at Arvada, Wyo., and Animas River at Aztec, N. Mex., were caused by general rains covering the entire basin.

The floods on the Arkansas, Big Horn and North Fork of Shoshone rivers were caused by a series of separate cloudbursts occurring in different parts of the drainage area, and so timed as to cause the resulting floods to converge at the point of measurement.

The characteristics of these floods (C_F) as determined by the proposed formula are presented in the following table:

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* District Engineer, United States Geological Survey, Denver, Colo.

FLOODS IN ROCKY MOUNTAIN REGION ARRANGED IN ORDER OF MAGNITUDE

STREAM	Date	DRAINAGE AREA (SQUARE MILES)		MAXIMUM DISCHARGE			T	R	$\frac{C}{F}$
		Total	Causing Flood	Peak Flow	Peak Minus Basic Flow	q			
Arkansas River at Pueblo, Colo.*	June 3–5, 1921	4,730	550	103,000	99,300	179	18	2.50	1,740
Powder River at Arvada, Wyo.†	Sept. 21–Oct. 2, 1923	6,050	6,050	95,000	95,000	15.8	112	1.37	888
Big Horn River at Thermopolis, Wyo.‡	July 23, 1923	8,080	5,000	29,800	21,800	4.4	170	.58	41
North Fork of Shoshone River near Wapiti, Wyo.§	July 22, 1923	800	200	8,100	6,600	33	8	.205	2,210
Animas River at Aztec, N. Mex.‖	Oct. 6, 1911	1,300	1,300	30,000	27,000	21	60	.96	780

* Water Supply Paper, 487.

† Water Supply Paper, 520, p. 119.

‡ Water Supply Paper, 520, p. 112.

§ Water Supply Paper, 520, p. 114.

‖ Water Supply Paper, 309, p. 247.

A comparison of the results of the general storm type with those given in Table 22 of the Committee's report shows the following:

Powder River, at Arvada, with its value of 888, agrees closely with that for White River at West Hartford. The concentrated storm run-off (R), however, is only 1.37 inches as compared with an estimated value of 6 inches. There is also a close agreement with the flood on the Kennebec River at Waterville, which had a value of 907. But again, R was less than half that of the Kennebec. T was 112 hours against 77 hours for the Kennebec.

The extremely high discharge of this flood, which was the greatest in the forty-seven years settlers had observed the river, is shown by the following table, which gives the ten highest floods of record at Arvada:

Date	Second Feet
September 29, 1923	95,000
June 16, 1925	50,000
April 5, 1924	21,000
June 19, 1920	10,700
March 7, 1929	10,300
May 12, 1920	9,000
July 26, 1923	8,800
July 10, 1926	8,700
August 15, 1927	7,750
June 3, 1921	6,680

The Animas River flood had a characteristic of 700 which lies between the values for the Kennebec at Waterville and the Connecticut River at Sunderland. T (60), however, is somewhat less than for the other streams, and R (.96) is very much less than for the Kennebec and Connecticut floods. To show the relative size of the Animas flood, which was the greatest known on the river, the three highest floods of record are given:

Date	Second Feet
October 6, 1911	30,000
September 6, 1909	16,000
June 2, 1914	9,360

The 1914 flood was apparently due to melting snow and not to general rains.

In contrast with the Powder River and Animas floods, that on the Big Horn, although the greatest in at least thirty years, had a flood characteristic of only 41 and a value for R of only 0.58. The annual highwater on the Big Horn, occurring usually from the middle of May to the middle of July, is caused by melting snow. In several years a discharge of about 20,000 second feet has occurred. The flood here under discussion occurred the latter part of July, and was caused not by melting snow but by a series of cloudbursts within a gross area of about 5,000 square miles.

The following table gives the results of the highest discharges on Big Horn not due to melting snow:

DATE	Second Feet
September 27, 1923	25,500
April 7, 8, 1924	16,200
March 11, 1929	13,600
July 11, 1926	9,750

It will be noted that except for the flood of September 27, 1923, which occurred within about two months of the maximum flood, and was nearly as great, the other floods due to rain were very much less.

The cloudburst types of flood have very high flood characteristics far exceeding those of the general storm type. The time of concentration is very much less, and the equivalent run-off very small.

From the meager information available it appears that floods in the Rocky Mountain region caused by general storms have flood characteristics similar to the New England floods having the highest characteristics. The equivalent run-off, however, is much less, and the flood period generally shorter. The cloudburst floods which are the more prevalent type have characteristics far exceeding the general storm type, with a very short period of flood.

From the foregoing discussion it is evident that while the Flood Committee's formula gives value C_F for general storm types of floods in the Rocky Mountain region comparable with those in New England, it does not fit the most prevalent type of floods.

LEROY K. SHERMAN (by letter):* I have reviewed with great interest the report of your Committee on floods. For some time I have made a study of flood flows on the Illinois River and its tributaries. These studies have included the relation between the hydrographs of rates of run-off to the corresponding rainfall on the drainage areas. Therefore the Committee's analysis and comparison of run-off by means of typical hydrographs is of special interest.

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* Consulting Engineer, Chicago, Ill.

I agree with and would emphasize the Committee's statement: "The flood hydrograph resulting from a given storm on a stream is the best key to the behavior of that stream with other storms." Figs. 6 and 8, showing the effect of shape of drainage area and the effect of difference in velocity of flow, indicate how futile is any attempt to correlate the relation of rainfall to rate of run-off by means of a formula, based only upon some relation of size of drainage areas, — a formula of the type $Q=CA^n$.

The reliability of the "rational method" in sewer design comes from the fact that it is a general procedure rather than an empirical formula confined by limiting assumptions. There is no reason why the "rational method" may not be applied to large drainage areas by using a known hydrograph and known rainfall as a key to furnishing the time of concentration, velocity of flow, and per cent run-off for compiling the hydrograph of run-off from any other rainfall.

The formula for peak flow $Q=C_F\sqrt{A}\ R$, submitted by the Committee, is a useful approximation. The procedure suggested by the Committee for the computation of the entire storm hydrograph is of far greater importance.

I find that the peak flow on a hydrograph is decidedly affected by the width of the lateral area tributary to the stream. The procedure of Major Pettis, referred to in the report, which recognizes this effect of lateral width is fundamentally sound and important.

The hydrographs considered in the report are for a single storm. On the Illinois River a flood is not caused by any single storm of great intensity. It is due to a succession of storms extending intermittently over several weeks; that is, the head end of the hydrograph of the second storm is superimposed upon the tail end of the first storm. This is a common situation, but it does not complicate the evaluation of the composite hydrograph.

There are several incidental points in the report on which I would briefly comment.

Total Flood Period. — The Committee's statement, that the "total flood period is a constant for a given point on a stream," is true for maximum flood or the heaviest downpour that may occur during the time of concentration. Such a rainfall is of very rare occurrence. In general, "total flood period" is the time or duration of the storm plus the time of concentration.

Pondage. — The terms "pondage" and "storage" have been frequently misapplied in river hydraulics.

I suggest the following:

"Storage" is stream flow, collected in a basin, which does not automatically drain out with a falling stage of the stream.

"Pondage" is stream flow retained at some particular reach of a stream during a rising stage and delivered during a falling stage. Pondage usually reduces rate of flow on the upper end of the hydrograph, increases rate of flow on the tail end of the hydrograph, and lengthens the "total flow period." Pondage may or may not reduce the peak flow, depending on duration and rates of precipitation. Pondage takes place only at certain points when and where the rate of discharge below that point is less than the rate of inflow immediately upstream from that point.

The important point I wish to make is this: there is no pondage in any reach of stream of normal cross section. The rate of flow is nowhere reduced.

The volume due to any depth of water in the normal sections is not pondage. It is merely water in transit. In this statement I differ with the Committee's statement on page 371.

Constant Velocity. — On page 370 is the statement: "In many cases the velocity appears to approach a fixed quantity." This is in accord with my experiments and observations to the effect that increase in flow divided by increase in cross section, or flood wave velocity, is constant at high river stages. (See Journal, Western Society of Engineers, August, 1923, paper on "Flood Waves," by L. K. Sherman.)

In conclusion, I would commend the report of the Committee as one of the most constructive pieces of work ever presented on flood hydrology and the relation of run-off to rainfall.

Closing Discussions by Members of Flood Committee

H. K. Barrows:* The fundamental difference between conditions in New England and California, both as to river regimen and flood control by storage reservoirs as well as the agencies and basic legislation available for storage projects, has been emphasized by Mr. Gross.

First of all, the distribution of rainfall during the year is much more uneven in California than in New England. Here we have approximately the same average monthly rainfall the year round, while in California a maximum is reached during the winter months, and at other times of the year rainfall is comparatively slight.

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* Consulting Engineer, Boston, and Professor of Hydraulic Engineering, Massachusetts Institute of Technology.

The use of water for irrigation purposes is a paramount need in California, but practically unknown in New England. The formation of water storage, irrigation and water supply districts has consequently reached a much more advanced stage in the West than in New England.

Progress is being made, however, toward enabling legislation for storage reservoirs here in New England, for the need for this has become acute.

In this connection it will perhaps be pertinent to outline briefly the work and recommendations of the Advisory Committee of Engineers on Flood Control, Vermont, of which the writer is a member and also consulting engineer.

This committee was formed as a result of the flood of November, 1927, and has been investigating the subject of flood relief for Vermont since 1928. Its final report, dated December 15, 1930, recommends the construction of power-storage reservoirs as the only practical means for flood relief in Vermont. All the principal river systems of the State have been thoroughly surveyed and investigated, and it has been found that in nearly all cases power-storage reservoirs can be built at such a cost as to be worth while for power development and incidentally be effective in respect to flood relief.

A basic enabling law for storage reservoir construction is now under consideration by the State and the committee recommends the immediate construction of two power reservoirs upon Winooski River, along with certain channel improvements, as the initial step in the work.

Another interesting feature of this committee's report is the effect resulting from the storage reservoir systems upon tributaries of the Connecticut River in Vermont upon the flow of the main river. These reservoirs would control some 2,700 square miles — or about 40 per cent of the drainage area of the main river at Turners Falls, Massachusetts, and would add some 1,700 second feet to the low water flow or more than double this at Turners Falls — at a relatively low cost for the increase in primary power thus created.

The writer has been greatly interested in the admirable discussion presented by Mr. Matthes, and appreciates his point of view regarding the likelihood of error in the use of flood damages as an index to the permissible cost of permanent protective works.

It is true that, as in 1927 in Vermont, many items of damage would not be repeated or included in a later flood. This is often, however, because new and better construction has been effected, as a result of the flood, not subject again to the same flood damage. Future construction may, however, introduce additional potentialities for flood damage, not now foreseen, which may offset the foregoing.

After all, such computations as a basis for the justification or exclusion of flood relief works are uncertain at the best, and are only of aid in helping one's judgment in such matters.

Mr. Matthes' suggestion as to flood zone tablets is a good one. While some interest has been shown in this respect in certain locations in Vermont, no comprehensive work of this kind has been done.

As a member of the Flood Committee, the writer wishes to express his appreciation of the interest taken in its report, and especially for the discussions presented by non-members of the Society, which have been very welcome.

S. STANLEY KENT:* The writer would join with Professor Barrows in thanking the engineers who have contributed to the discussion of the Flood Committee Report. Many of these discussions have brought up interesting points in connection with the Committee's report, and the writer will take up the questions which have been raised with regard to Chapter IV, "Flood Factors for New England," and Chapter V, "Flood Formulæ for New England."

Some of the questions raised by Mr. Horton in his discussion of the report indicate that perhaps the Committee did not make its proposed method of treating flood problems entirely clear, and on that account a brief restatement is included.

Flood estimates are desired for the purpose of determining the amount of water to be provided for in the case of new construction or the protection of existing structures. To put the question concretely, it might be worded, "What would happen on a particular stream if it were subjected to a storm similar to that of the 1913 storm over the Miami drainage area?" It is, of course, impossible to give a precise answer to such a question, and estimates of the possible storm and of the resulting flow are necessarily of an approximate nature. What is desired is a rational basis by which a reasonably intelligent estimate can be made.

The magnitude of the storm and the size and type of the drainage area are obviously the determining factors. In the formula proposed by the Committee the term "R," the run-off in inches, takes care of the magnitude of the assumed storm; the term "A" is the size of the drainage area in square miles; and the term "C_F," the flood characteristic, takes care of the flood characteristics or type of the particular drainage area. The value used for the term "R" will be based on the general experiences of the region considered and the degree of protection desired; the value of "A," from the maps of the drainage area and the value of the flood characteristic; "C_F," preferably from a hydrograph resulting from a single short storm of even moderate intensity at the place in question, but if no flood hydrographs are available it must be estimated from the general conditions on the drainage area compared with other drainage areas where the values of "C_F" can be determined from flood hydrographs.

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Mr. Horton has questioned the use of the term "R," the run-off in inches, in place of "P," the rainfall in inches. It would seem to the writer that either of these expressions could have been used. However, it is the amount of run-off and not the amount of rainfall that actually produces floods. The rainfall term "P," with a coefficient of run-off, can be substituted directly in place of "R" in the formula if Mr. Horton prefers. Pages 350 to 354 of the report were devoted to rainfall-run-off relations. The Committee, in considering the probable values in the run-off "R," has considered both rainfall and run-off data in order to make use of all the available information, although Mr. Horton accuses the Committee of failure to do so. The writer believes that for storms within the concentration period there is an approximate relation between the total amount of run-off and the peak flows, but that there will be wide variations between the total rainfall and peak flows on account of the large differences in the per cent of run-off.

Mr. Horton expresses regret that the Committee did not take advantage of the "unusual opportunity to determine the relation of flood rainfall to peak run-off." Had this been done it would have given such a relation for the particular conditions existing at the time of the November, 1927, flood. The result thus obtained would have had but little bearing upon these relations for a similar storm occurring, say, in April or in August. Furthermore, the rainfall data for this storm are not nearly as complete as is assumed by Mr. Horton. The table of previously unpublished records of rainfall given on page 307 was included in the report to indicate this absence of complete information. It is entirely probable that 50 per cent more rain fell in many places than was recorded by any rain gages in the vicinity. The largest peak flows and the greatest damage occurred in those regions where the rainfall data were far from being complete. Any attempt to determine the relation between the rainfall and the peak flow in such localities would have been the wildest guesswork. The rainfall contours shown on Fig. 2

represent an approximate distribution of the general storm as determined from most of the rainfall measurements reported. Some of the records given on page 307 are not at all consistent with the rainfall contours as given in Fig. 2. As is stated on page 307, these records "suggest the possibility that the rainfall may have been 'spotty,' and also, perhaps, much heavier in some localities than is indicated by the contours in Fig. 2."

The writer cannot agree with Mr. Horton when he says that "the use of flood run-off instead of flood rainfall is claimed as the main advantage of this formula." On the contrary, it would seem that the introduction of the flood characteristic, "C_F," which is a measure of the flood-producing characteristics of a drainage area, and which can be determined quantitatively from flood hydrographs, constitutes the principal advantage.

The purpose of determining the relation between the net flood run-off and the peak flow is not for the purpose of arriving at the peak flow, as is intimated by Mr. Horton, but rather to evaluate the drainage area characteristic; and this, once determined, can be used for estimating the peak flow of greater floods at the same location and also for use on other similar drainage areas where no hydrographs are available for a direct determination. The formula proposed by the Committee was developed from theoretical considerations instead of from Table 28, as Mr. Horton seems to imply. Tables 22 and 28 were included to illustrate the methods pursued, and give values of the flood characteristic, "C_F."

Early in the Committee's studies it became apparent that some definite allowance had to be made for the flood-producing characteristics of a watershed. Several different methods were tried out in the search for a measure of these characteristics. The time required for the peak flow to be reached was studied, and it was found that whereas in many cases this method offered a basis of comparison between the flood-producing qualities of different drainage areas, there were some marked exceptions to this method. In some cases a comparatively small, quick run-off area immediately above the gaging station produced a peak shortly after the period of greatest rainfall which was followed by a well-sustained flood flow for several days of slightly lesser magnitude. The Quaboag River at West Brimfield is an example of this type. It eventually became evident that the shape of the entire flood hydrograph was necessary in order to obtain the whole story.

The slope of the streams was also considered. However, it soon became evident that the distribution of the slope, the nature of the stream channels, and the effect of contracted sections were of great importance. While a topographic map will show, even at a glance, whether a stream will have rapid or slow run-off characteristics, the writer questions whether it gives sufficient information to permit the characteristics to be determined analytically. The stream channels themselves occupy entirely too small a space on the usual topographic maps. The writer questions whether the information given on any topographic, forest and soil maps that are available is sufficient to do more than give a general indication of the flood characteristics of a drainage area. Even with the most complete maps of this sort it would be very difficult to estimate how the flow from the various branches and tributaries would synchronize to produce a quick, sharp peak, or be just far enough apart in their time of peak flow to produce a moderately rounded hydrograph. As is stated on page 377 of the report, "The problem is extremely complex when approached analytically from its component parts of distances, slopes and pondage." All these factors are automatically reflected in the flood hydrograph. The effect of land surface slope, stream slope, drainage density, vegetational cover, and character of soil, as listed by Mr. Horton, make their impression upon the flood hydrograph. In fact, it would seem that the flood hydrograph was in effect an integration of the influence of all these various factors. The writer believes that the flood hydrograph affords a much simpler, direct and more accurate method of correlating "flood discharge with the principal physiographic factors" than could be obtained by analytical determination of these factors.

This method of determining the flood producing characteristics of a drainage area from flood hydrographs is admittedly limited to those streams for which flood hydrographs are available. The number of gaging stations equipped to give a continuous hydrograph has become large and is constantly increasing. As the flood characteristics of these streams are determined, it will afford an ever increasing amount of data for use in estimating the flood characteristics of other streams on which no hydrographs are available.

With regard to the rainfall formulæ on page 344, Mr. Horton is, of course, correct in suggesting that the use of "R" instead of "P" in the last formula on the page was a typographical error. The formula should read, $P=0.911\ T^{0.3}\ F^{0.27}$. Mr. Horton has worked out the results of applying this formula for frequencies of much longer periods, and arrives at a figure of 52 inches in 24 hours for a 100,000-year frequency. This period is so far beyond the length of observations used in deriving the formula that these computations would not appear to have any particular significance.

The Committee fully realizes that its treatment of the problem of melting snow was also entirely on an empirical basis. The data which were available consisted of certain reports on depths of snow, stream run-off, rainfall, and maximum and minimum temperatures. Information on sunshine, wind, humidity and other important factors was missing. The formula derived, while entirely of an empirical nature, does indicate an average result based on the available information. With more complete data, a more accurate and rational solution of the problem can probably be reached. It seems that in general the public is inclined to place a greater emphasis upon run-off from melting snow as the cause of floods than is warranted by the facts.

Mr. Creager in his discussion has pointed out a necessary correction in the following statement on page 366 of the report: "Hence, the conclusion can be drawn that for identical storms (within the concentration period) on similarly shaped watersheds having the same velocities and negligible pondage, the peak flows will vary directly with the square root of the drainage areas." As Mr. Creager says, this statement is not correct for "identical storms." Had the expression "similar storms" been used instead of "identical storms," the writer believes the statement would have been correct. In this connection similar storms would be defined as storms having the same ratio between their duration as the ratio between the homologous dimensions of the similarly shaped watersheds.

There are several reasons why the method applied by Mr. Davenport in making a comparison of the flood characteristics of the Penobscot and Kennebec River basins cannot be applied in the way in which he has used it. His method consists of arranging the 24-hour flows for these two streams in their order of magnitude for the years between 1902 and 1926, inclusive, and then comparing the relative magnitude of the fifth, tenth, fifteenth, etc., highest days. Mr. Davenport mentions the fact that a point may be reached "where time intervals of less than a day must be used in order to assure proper definition." The ratio of the peak flow to the maximum 24-hour flow is something like 10 per cent greater in the case of the Kennebec at Waterville than for the Penobscot at West Enfield. The length of the concentration period is a matter of much greater importance than the intervals of less than a day. The writer listed the 25 days of maximum flow on both these streams during the period considered by Mr. Davenport, and found that 20 out of the 25 in the case of the Penobscot, and 15 out of the 25 in the case of the Kennebec, were during the spring months when the flow came in large part from melting snow. At such a time the temperature, the amount and condition of the snow, and the size of drainage area are the important factors, and with the same conditions as regards snow and temperature on two adjoining drainage areas, the total flow will tend to vary directly with the magnitude of the drainage areas. A series of figures based upon flows at such a time would not appear to shed any particular light upon drainage area characteristics. The effect of the length of the concentration period would also militate against the usefulness of such a series, even at such times as no melting snow occurred. The concentration period of the Kennebec River at Waterville is in the vicinity of 24 to 30 hours, while that of the Penobscot River at West Enfield is about 50 to 60 hours. If each of these drainage areas should be subjected to a series of the same storms varying in duration from 5 to 50 hours, then all of these storms would produce peak flows on the Penobscot River at West Enfield approximately proportional to the inches of flood run-off. On the Kennebec River, however, those storms of more than 20 to 30 hours' duration would produce very differently shaped hydrographs from those resulting from storms of less than 20 hours' duration, and the longer storms would fail to give a true indication of the flood characteristics of this drainage area. The writer believes that the neglect to consider the importance of the concentration period has been responsible for much of the lack of progress in the rational analysis of flood flows on rivers and streams.

Mr. Davenport expresses doubt as to the validity of a comparison of these two drainage basins based on the 1909 flood for the Penobscot and the 1901 for the Kennebec. The three-day rainstorm which he refers to for the Penobscot was, in all probability, just as well within the concentration period for that river as was the two-day storm accompanied by a thaw within the concentration period of the Kennebec. The actual flood run-off in inches over the two drainage areas was almost identically the same. A consideration of the flood characteristic curves for these two floods given in Fig. 17 of the Committee's report makes it evident that for storms of equal run-off limited in duration to the concentration period, the unit rate of peak flow on the Kennebec will inevitably be much greater than on the Penobscot. The September, 1909, storm included both of these drainage areas, although the run-off was greater on the Penobscot. The storm probably began sometime during the twenty-sixth, but on account of the preceding dry weather it is doubtful if much run-off occurred before the twenty-seventh. The greatest 24-hour flow of the Kennebec at Waterville occurred on September 29; by October 1 the flow was down to 40 per cent of the peak day, and by October 2, to less than 25 per cent of the peak day. On the Penobscot

River at West Enfield, the highest day occurred on September 30, and on October 1 the flow was 67½ per cent of this peak, and on October 2 it was above 50 per cent. The writer has no hydrograph of the flow of the Kennebec for this flood, but even a casual examination of the 24-hour flow figures for the two rivers discloses a marked difference in their behavior.

The differences in concentration period and the shape of the hydrograph are two of the important reasons why it is necessary to consider the flood problem on any river as a problem by itself. The type of storm producing the worst flood conditions will depend in a large measure upon the size and the flood characteristics of the drainage area.

When it comes to the question of the frequencies of various run-offs from the New England storms, the data are admittedly very sketchy. In making its conclusions of 3 inches for the occasional flood, 6 inches for the rare flood, and 8 inches for the maximum flood, the Committee has in effect assumed greater intensity of rainfall over a shorter period for drainage areas having a short concentration period than for those having a long concentration period. In those cases where the concentration period varies directly with the size of the drainage area, this in effect assumes that the probability of a more intense rainfall on the smaller drainage area balances the probabilities of a general storm of equal run-off but of longer duration covering the entire area of the larger watershed. The evidence given in Table 25 and Table 26 points towards such a conclusion. We also have the general evidence that a concentrated net flood run-off of between 3 and 3½ inches has occurred about once in 50 years on most of the streams of New England for which flood records have been available for any length of time. Floods having a net equivalent concentrated flood run-off of between 5 and 6 inches, such as the 1923 flood on the Penobscot and the 1927 flood on certain streams in Vermont, have been of rare occurrence. There are no records of an 8-inch flood in New England. As is stated on page 405 of the report, this figure was chosen as a maximum on the basis of the 1913 flood on the Miami River, which it is believed was the greatest flood on record in the northeastern section of the United States.

The writer was particularly glad to receive the discussion by Mr. Follansbee on account of the data which he gives covering the streams in a different part of the country. However, the writer would make a somewhat different interpretation of the data given by Mr. Follansbee, and believes that the high values of the flood coefficient C_F which he obtains for the Arkansas at Pueblo, Colo., and the North Fork of the Shoshone near Wapiti, Wyo., are due more to differences in the flood characteristics of these drainage areas than to the difference in the type of storms. The writer assumes that a cloudburst is simply an exceedingly heavy rainstorm. It usually means a greater per cent of run-off and probably a quicker run-off over the ground to the water courses, and for most drainage areas somewhat higher peak flows, than would be produced by the same volume of run-off due to an ordinary storm even though limited in duration to the concentration period.

From the references given in Mr. Follansbee's discussion it appears that the flood on the Big Horn was due to a series of cloudbursts extending over several days, and it is a question whether this succession of storms would not extend beyond the concentration period. From the data given by Mr. Follansbee the writer obtains a value for the flood coefficient C_F of 532 instead of 41, which is given in Mr. Follansbee's table. This means three of the flood coefficients, C_F, vary between 532 and 888, while the other two drainage areas have computed coefficients of 1,740 and 1,710, respectively. The first three are within the common range of the flood characteristics of New England streams. The last two are much higher than anything which the Committee found for New England. The writer is not personally familiar with these last two streams, but from the descriptions of them in Mr. Follansbee's references it would appear reasonable that they should have very high run-off characteristics. The writer doubts if there are any streams in New England so conducive to quick run-off as these two rivers. On most of the New England streams those parts having the steeper slopes are very much broken up by a succession of falls and cascades. This is particularly true of the smaller branches which feed the main streams and on which the slopes are steepest. Such falls and cascades serve to use up the energy of the water, but have little effect on the velocity of flow of the river considered as a whole. There are numerous contracted sections, and the trees and bushes offer considerable resistance to the flow at the higher stages. The writer believes that it would be possible artificially to construct a watershed having flood characteristics at least three or four times as high as anything found in nature in New England. With smooth sloping sides to the valleys, and with ample and smooth water channels of more or less uniform slope, and cross section affording little opportunity for channel pondage or falls, an exceedingly quick and rapid concentration of run-off could be obtained. Such a drainage area can be imagined in which the average velocity of flow would be at least 15 miles per hour, and even with the ordinary distribution of drainage area, this would result in a concentration period of but little over 1 hour for 100 square miles, between 6 and 7 hours for 2,500 square miles, and about 13 hours for 10,000 square miles. Such a drainage area might easily have a flood characteristic, C_F, of 3,000, and with a densely arranged distribution of area the figure could be 4,000 or even higher.

The writer believes that the Arkansas and the North Branch of the Shoshone approach this situation much more closely than do any of the New England streams. The roofs and smooth-paved courts and streets in a thickly settled community result in an approach to just such conditions. A much greater velocity of flow is quickly noticed when a dirt road is changed to a paved street. The "rational method" makes an allowance for this changed condition by increasing the value assumed for C, the per cent of run-off. Undoubtedly the smooth paving does increase the per cent of run-off, but the higher velocities are an additional important factor.

The Committee agrees thoroughly with Mr. LeRoy K. Sherman when he says in his discussion, "I find that the peak flow on a hydrograph is decidedly affected by the width of the lateral area tributary to the stream. The procedure of Major Pettis, referred to in the report, which recognizes this effect of lateral width is fundamentally sound and important." The Committee recognizes the assistance which it received from Major Pettis' treatise on "A New Theory of River Flood Flow." Much of the analysis of drainage area characteristics on pages 362 to 375 was carried out along the lines suggested by Major Pettis in his treatise. The writer subscribes to Mr. Sherman's definition of "storage" and "pondage," and agrees that under some conditions "pondage may or may not reduce the peak flow, depending on duration and rates of precipitation." However, for uniform storms the effect of pondage is usually to reduce flood peaks, and the volume of water required to raise the water surface from normal to flood stage does tend to reduce the peak flow at points lower down, excepting in such cases where the flattened peaks thus caused coincide more closely with a later peak from tributaries below.

Mr. Jarvis is correct in assuming that the maximum for New England recommended by the Committee rates as high as 80 per cent on the Meyers scale. It is true that New England has never experienced a flow of this magnitude, and that 50 to 60 per cent on the Meyers scale represents the greatest floods on record in New England. However, had the Miami storm of 1913 been centered over New England, it is probable that some flood rates approaching 80 per cent on the Meyers scale might have resulted. The maximum of an 8-inch flood was purposely presented as something greater than has ever been experienced, and hence is a distinct improbability as far as any particular watershed is concerned.

However, in the case of important structures, the failure of which might result in great loss of life, it would hardly seem reasonable to assume that such a flood was an absolute impossibility in New England.

Mr. Jarvis in his discussion refers to "the remarkable assumptions that are made for the sake of simplicity." It is believed that in all cases the nature of the assumptions has been clearly stated and the variations from the assumptions referred to. In any attempt to treat such problems involving varying factors in a rational manner, it is usually necessary to make certain assumptions of the conditions existing, which, while not strictly in accordance with what actually takes place, nevertheless do in a fair measure represent the same conditions. The committee would prefer to look upon its results, as far as the derivation of a flood formula is concerned, as an adaptation of the "rational method" to the larger drainage areas, rather than as the derivation of an entirely new formula. On pages 390 and 392 of the report the great similarity between the formula developed by the Committee and other formulæ is pointed out, together with the similarity between these formulæ and the "rational method."

At one of the first meetings of the Committee, the chairman expressed a hope that the Committee would succeed in adapting the "rational method" to the larger drainage areas. The general treatment of drainage area characteristics and the derivation of the formula proposed were completed and the report written in nearly final form before it was discovered that the formula arrived at was in effect simply a variation of the "rational method" frequently used in sewer design.

The writer would suggest the possibility of applying the same variation to the smaller drainage areas, *i.e.*, separating the constant C in the rational formula $Q = C\,i\,A$ into two parts, one representing the per cent of run-off, the other the drainage area characteristic. This drainage area characteristic could be evaluated from hydrographs in exactly the same way as has been suggested in the Flood Committee Report.

ARTHUR T. SAFFORD:* The discussion includes valuable contributions from many engineers. In general, the references by non-members to the work of the Committee and its report are favorable, and much contrasting and valuable data are given, bringing out local differences and new questions which emphasize the danger of using New England data for other rivers of the United States.

The Committee feels that it gave this question unusually careful consideration, and has not attempted to give its work country-wide application, although it believes that the use of the flood hydrograph and the adaptation of the "rational method" to the larger drainage areas will aid in the solution of many flood problems, and constitute the best methods so far suggested.

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* Chairman, Boston Society of Civil Engineers Flood Committee; Engineer, Proprietors of Locks and Canals, Lowell, Mass.

At this late date, nearly five years after the November flood of 1927, and more than two years after the report of the Committee, it is possible to judge better of the effects and reactions from this flood. In spite of the long-continued business depression, the areas and communities most devastated, particularly where the loss of life and property were greatest, have risen above their losses; railroads, highways and bridges in the flooded districts and communities hardest hit collectively seem to be better physically than before the flood; and the testimony from these localities is clear on this improvement. Nothing will ever make up for the loss of life and individual property, which will always be the toll of record-breaking floods.

Generally speaking, however, few lessons have been learned from that particular flood beyond the actual reconstruction of existing structures.

Controversial questions over floods, which include frequency of record-breaking freshets, maximum run-off to be expected, suddenness and height of peaks, insurance against losses on a large scale, effect of flood reservoirs, and the many economic questions which control their construction, are just where they were, and are likely to be as controversial in the future when the next great flood occurs. Neither the report of this or other flood committees, or the discussions which follow, will ever settle many of these controversial questions, but they must be taken up anew by public officials, engineers and committees as often as these great floods occur.

At the time of writing, New England, or at least the middle and southerly parts, is going through a series of below-normal, or dry, years, already three in number. With all the records of rainfall and run-off and the studies and records of the United States Weather Bureau, United States Geological Survey, and other Federal and state activities, the future of weather can never be anticipated, and the most any committee can expect is to add its part to the general knowledge of the subject for future engineers and other statisticians to study.

OF GENERAL INTEREST

PROCEEDINGS OF THE SOCIETY

MINUTES OF MEETINGS

Sanitary Section

DECEMBER 7, 1932. — A regular meeting of the Sanitary Section of the Boston Society of Civil Engineers was held on December 7, 1932. Twenty members and guests met at Patten's Restaurant at 6 P.M. for dinner.

The meeting was called to order in the Rooms of the Engineering Societies of Boston at 7.15 P.M., with forty-one present.

Mr. Frank L. Flood, Assistant Engineer, Metcalf & Eddy, spoke on "A Review of Recent Developments in Sewage Treatment Works." The talk was illustrated with lantern slides and dealt in particular with the development in mechanical equipment for sewage and sludge treatment works.

Dr. G. P. Edwards, formerly Principal Assistant Chemist, sanitary district of Chicago, spoke briefly of the demonstration sludge denaturing and incineration plant at the Chicago West Side plant.

The meeting adjourned at 8.30 P.M.

FRANK L. FLOOD, *Clerk.*

Northeastern University Section

NOVEMBER 17, 1932. — The first formal meeting of the Northeastern University Section was held on November 17, 1932, in Room L, at the University, at 7.30 P.M.

An informal meeting was held in October in the form of a joint excursion with other members of the Boston Society through the new East Boston Tunnel.

The business meeting was conducted by Prof. H. B. Alvord in the absence of the Chairman. After discussion as to the best means of stimulating interest in the newly reorganized student branch the following were elected as a ways and means and membership committee:

Juniors (fourth year men): L. M. Pittendreigh, A. Minichiello, W. F. Wolfrum.

Middlers (third year men): J. Dearborn, I. W. Kendall, P. J. Leonti.

Sophomores (second year men): F. J. Kihs, A. Kirkland, F. J. Gallassi.

Mr. Frank L. Flood, Northeastern University, 1922, of Metcalf & Eddy then gave an illustrated talk on "3,500-Mile Inspection Trip, Visiting Sewage Disposal Works in the United States."

HENRY B. ALVORD, *Chairman,*
Pro Tem.

DECEMBER 7, 1932. — A meeting of the Northeastern University Section was called to order by President Anthony Tedesco, at 2 P.M., in Bates Hall.

The first business of the meeting was the election of a clerk. Messrs. Columbo, Crouch and Schow were nominated. Ballots were cast and Mr. Schow, receiving the highest number of ballots, was declared elected to that office.

Mr. R. W. Horne, President of the Boston Society of Civil Engineers, explained the organization of the Society and outlined the advantages derived from membership in this Society.

Application blanks were distributed to those wishing to join the Northeastern University Section.

Mr. J. L. Herber, Engineer for the International Cement Corporation, gave an instructive lecture on "High Early Strength Portland Cement." The lecture was supplemented by colored slides and a film showing how this new cement is used in difficult or exacting engineering construction.

The meeting adjourned at 3.20 P.M.

BRUCE SCHOW, *Clerk.*

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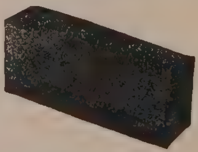

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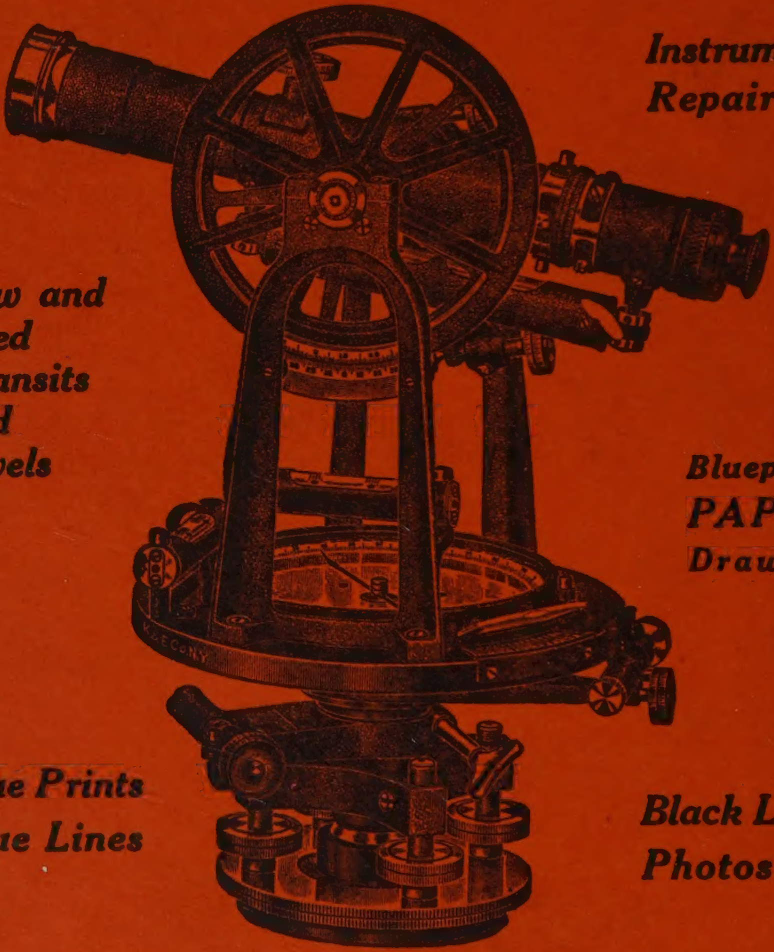

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